Mu'tah University

Deanship of Graduate Studies

Medical Devices Service Life Cycle Cost Management in Al Karak Hospital as a Case Study

by

Nisreen Hosam Jawabreh

Supervised by

Professor Salloom A. AL-Jibury, PhD, ME

Co-supervised by

Professor Omer N. Maaitah, PhD, CE

A Thesis Submitted To The Deanship of Graduate Studies in Partial Fulfillments the studies Requirements for the Degree of Master of Science in Engineering Management in Faculty of Engineering

Mutah University, 2014

الآراء الواردة في الرسالة الجامعية لا تُعبر
بالضرورة عن وجهة نظر جامعة مؤتة

بسم الله الرحمن الرحيم

MUTAH UNIVERSITY

Deanship of Graduate Studies

جامعة مؤتة

عمادة الدراسات العليا

نموذج رقم (١٤)

قرار إجازة رسالة جامعية

تقرر إجازة الرسالة المقدمة من الطالبة نسرين حسام الجوابرة الموسومة بـ:

Medical Devices Service Life Cycle Cost Management in Al Karak Hospital as a Case Study

استكمالاً لمتطلبات الحصول على درجة الماجستير في **الادارة الهندسية.**

القسم: هندسة النظم الصناعية.

	التوقيع	التاريخ	
أ.د. سلوم أحمد الجبوري		22/12/2014	مشرفاً ورئيسا
أ.د. عمر نواف المعايطة		22/12/2014	عضواً
أ.د. حسين المجالي		22/12/2014	عضواً
أ.د. احمد سعيد السلايمة		22/12/2014	عضواً

عميد الدراسات العليا

K. Baran

د. علي الضمـور

MUTAH-KARAK-JORDAN
Postal Code: 61710
TEL :03/2372380-99
Ext. 5328-5330
FAX:03/ 2375694
e-mail: dgs@mutah.edu.jo sedgs@mutah.edu.jo
http://www.mutah.edu.jo/gradest/derasat.htm

مؤته – الكرك – الاردن
الرمز البريدي : ٦١٧١٠
تلفون :٩٩-٠٣/٢٣٧٢٣٨٠
فرعي 5328-5330
فاكس 375694 ٠٣/٢
البريد الالكتروني
الصفحة الالكترونية

Dedication

I dedicate my thesis to my aunt Nadia Al Tamimi soul.

Nisreen Jawabreh

Acknowledgment

Praise and thanks be to the Almighty Alla for giving me the patient, health and strength to complete my thesis.

I am deeply indebted to my advisor Prof. Salloom Aljibury for his guidance, patient, support and his valuable suggestions and comments in the course of my master thesis study. I am also deeply indebted to Prof. Omer Maaitah for his valuable comments. I extend my gratitude to the committee members for their comments through the review of my thesis.

I thank my dear husband (Prof. Adel Abdel-Ghani) for encouragement during my master study. I am much indebted to him for his valuable advices that substantially improve the quality of my work. I am grateful for him in every possible way for using his precious times to read the thesis and for giving critical comments.

From the bottom of my heart with love, I thank my dear parents for their tender love care, and encouragement during my whole life. I am also thankful to my dear sisters (Eng. Abeer and Ghadeer) and brothers (Eng. Naser and Eng. Muhamad) for their support, encouragement, and loving during my whole life.

Finally I deeply thank my kids (Liyan, Zaid, and Banan) for their love, support and sacrificing in many funny things because of my unavailability for that, and also I appreciate deeply the support of my friend Boshra Khresha for her encouragement during the course of my study.

Nisreen Jawabreh

Table of Contents

Important Points

Content Page

List of Tables

List of Figures

List of Abbreviations

Abbreviation	Meaning
LCC	Life Cycle Cost
NPV	Net Present Value
MOH	Ministry of Health
UK	United Kingdome
DoD	U.S. Department of Defense
LCA	Life Cycle Assessment
NATO	North Atlantic Treaty Organization
PdM	Predictive Maintenance
PWC	Present Worth Cost
IT	Information Technology
PV	Present Value
FV	Future Value
AV	Availability
UNA	Unavailability
MTTR	Mean Time To Repair
MTBF	Mean Time Between Failures

Abstract

Medical Devices Service Life Cycle Cost Management in Al Karak Hospital as a Case Study.

Nisreen Hosam Jawabreh

Mutah University 2014

One of the most common important issues for decision-making is to select of the suitable model among a group of alternatives. Selecting the best alternative is with crucial importance for an efficient budget management. In governmental health sector in Jordan, criteria for the selection and purchase of medical devices focused on the safety properties, and the initial purchase price. Many decisions concerning the purchase of a medical device is usually relying on personal opinions rather than on the basis of life cycle costing information.

In this study, we implemented the concept of LCC to select between two alternative models from three different sets of medical devices, including two electrolyte models (Easylyte Plus and AVL-9810), two X-ray models (UD 150L–30E and KXO-50R) and two infant incubator models (Air shields C450 and Nestoret 5050) as case studies.

For LCC calculations, Kaufmann approach was used, which defines the operating profile, utilizing factor, the most critical cost parameters (i.e. failure rate and repair rate) and any related cost component (i.e. operating cost, maintenance cost).

Our results showed that LCC could improve the range and quality of information available for decision-making when a comparison is performed between two alternatives. When comparing the annual LCC values for each two alternative models, the key effective cost categories affecting LCC were the consumable power cost and/ or consumables costs and the maintenance cost. Results showed that LCC and device age are linearly related indicating the increase of the cost to maintain the device in service by increasing the device age. Paired t- test showed significant differences between each two alternative models in annual LCC estimates. In this study, the AVL-9810 displayed 25% lower annual LCC as compared with Easylyte plus model. Higher annual LCC value (4.4%) was found for UD 150L–30E than KXO-50R suggesting that KXO-50R is better alternative than UD 150L–30, even though KXO-50R has higher capital cost. The annual LCC estimate for Air shields C450 was 5% lower than Nestoret 5050 due to lower initial cost and maintenance cost.

In conclusion, LCC analysis used in this study is vital for decision making for justifying certain model selection among a group of alternatives based on total costs rather than on the initial purchase price of a device.

الملخص

ادارة كلفة دورة حياة الاجهزة الطبية اثناء خدمتها في مستشفى الكرك الحكومي كدراسة حالة

نسرين حسام جوابرة

جامعة مؤتة 2014

يعتبر قرار اختيار موديل الجهاز الطبي المناسب من بين مجموعة من البدائل احد اهم القضايا, حيت يعتبر البديل المناسب ذو اهمية حاسمة في إدارة الميزانية بكفاءة. تركز عمليات الشراء في القطاعات الحكومية الصحية في الاردن على خصائص السلامة و على السعر الاولي للجهاز. تعتمد الكثير من القرارات التي تتعلق بشراء الاجهزة الطبية على الاراء الشخصية بدلا من اعتمادها على المعلومات الخاصة بتكاليف دورة حياة الجهاز.

تم في هذة الدراسة تطبيق مفهوم التكاليف خلال دورة الحياة و ذلك للمساعدة في عمليات الاختيار من بين بديلين من الموديلات لثلاثة مجموعات من الاجهزة الطبية كدراسة حالة. شملت الأجهزة موديلين من أجهزة الألكتروليت (Easylyte Plus and AVL-9810) و موديلين من اجهزة اشعة اكس (UD 150L–30E and KXO-50R) و موديلين من اجهزة حاضنات الاطفال (Air Shields C450 and Nestoret 5050.)

تم استخدام طريقة كاوفمان لحساب كلفة دورة الحياة و ذلك من خلال تعريف التكالبف الناتجة عن التشغل للجهاز و عامل الاستخدام و حساب مقاييس التكاليف الحرجة(معدل العطل و معدل الاصلاح) و اي تكاليف اخرى ذات علاقة في تشغيل الجهاز و كلفة صيانته.

أظهرت النتائج ان التكاليف خلال دورة حياة الجهاز تحسن مدى و نوعية المعلومات اللازمة لاتخاذ القرار عند مقارنه تكاليف دورة الحياة السنوية لأثنين من البدائل. أظهرت النتائج ان العناصر الاساسية التي تؤثر على قيمة تكاليف دورة حياة الجهاز هي كلفة الطاقة و/أو المواد المستهلكة في تشغيل الجهاز و كلفة الصيانه. اظهرت النتائج ايضا ان العلاقة ما بين تكلفة دورة حياة الجهاز وعمره هي علاقة خطيه مما يدل على زيادة تكلفة ادامة الجهاز في الخدمة مع زيادة عمر الجهاز. بين فحص (t) المزدوج للمعنوية وجود فروقات معنوية ما بين الموديلات البديلة في تكاليف دورة الحياة السنوية.

في هذة الدراسة اظهر الموديل AVL 9810 أقل في تكاليف دورة الحياة السنوية 25% مقارنة بالموديل البديل Easylyte Plus. كانت تكلفة دورة الحياة السنوية للموديل UD 150L-30E مقارنة بالموديل KXO-50R أكبر بمقدار 4.4% , مما يدل ان الموديل UD 150L-30E هو بديل افضل مقارنة بالموديل KXO-50R على الرغم من انه الأعلى في الكلفة المبدئية. و كانت تكاليف دورة الحياة السنوية للموديل Air Shields C450 اقل بقدار 5% مقارنة بالموديل Nestoret 5050 و يعود ذلك الى الانخفاض في السعر المبدئي للجهاز و تكلفة الصيانه.

يمكن الأستنتاج من هذه الدراسة الى الاهمية الكبيرة لتحاليل التكلفة خلال مراحل الحياة لتبرير اتخاذ القرارات في أختيار موديل معين من بين مجموعة من البدائل, حيث تعتمد هذة الطريقة على التكاليف الكلية بدلا من التكلفة المبدئية للجهاز.

Chapter One
Introduction

1.1 General View

The continuous evolution and life cycle cost (LCC) analysis of medical devices have an impact on health services quality, and financial efficiency of the hospital long run costs.

Planning for this evolution and its subsequent implications became a major challenge in most decisions of health care organizations and their related industries (Bronzino, 2006). Therefore, there is a need to apply adequate management tools which optimize the development of medical technology that takes into account life cycle costs and improves health care services.

Successful management of technology will lead to a good coordination between the needs and the capabilities of staff and technology, respectively (Chien et al., 2010).

Various definitions could be found in literature for LCC analysis. According to Bronzino (1992), LCC analysis is an economic measure that is used to evaluate competing alternatives based on the estimated total cost of decision makers.

Life cycle cost is "a tool used during technology planning, assessment or acquisition either to compare high-cost, alternative means of providing a service or to determine whether a single medical device or technology has a positive or negative economic value" (Bronzino, 1992).

The strength of the LCC analysis is to monitor the cash flow impact of an alternative over its life span, instead of focusing solely on initial cost of the medical device.

Another definition of life cycle cost stated by Barringer & Weber, (1996), where they defined LCC as summations of cost estimates from inception to disposal for devices as determined by an analytical study and estimate of total costs experienced during their life (Barringer and Weber, 1996). Industry competitiveness depends on the cost, performance, and timely delivery of the product. Thus, an accurate, rapid, and robust product cost estimation model for the entire product life cycle is essential (Yeh and Deng, 2012).

In view of resources could be obtained for the healthcare system (i.e hospitals or health care centers), the effectiveness of the cost of new technology or purchasing new devices will be a key factor in its adoption.

The life cycle cost of a medical device is based on its accumulated cost during its life cycle. Usually the cost of the medical device is closely associated the benefits: cost ratio obtained from one device as compared to

other new or best alternatives (i.e. different sources and new technology to achieve the same purpose). Having an idea about cost effectiveness will be helpful for the decision makers and/or investment decisions which products (model) and sources will be most cost effective.

The presence of sophisticated healthcare systems, leads to the need for more effort to select convincing and sophisticated application for the medical device that meets patient needs with minimum cost. The customers do not need elegant technical solutions but also a device with the greatest 'value proposition' (Bronzino, 2006).

In general, it was estimated that the purchase price represents only 20% of the LCC of ownership (Bronzino, 2006; Salem, AbouRizk, & Ariaratnam, 2003). Other research estimated the acquisition cost is equal to 15% of the total cost of ownership for a device. That means the bulk of the life-cycle costs comes after the purchase, including 45% energy-related costs, 35% maintenance costs, and the remaining 5% for what is classified as other (Gager, 2012).

LCC uses Net Present Value (NPV) concepts. NPV is an important economic measure for projects or devices taking into account discount factors, cash flow, and time. Net present value calculations start with a discount rate, followed by finding the present value of the cash proceeds expected from the investment, then followed by finding the present value of the outlays, the net of this calculation is the net present value. Cash availability and strategies aside, when competing projects are judged for acceptance, projects with high NPVs usually win (Levander et al., 2014).

1.2 Importance of Life Cycle Cost Analysis

The selection and purchase of a medical device depends on the price and any probable risk to patients and/or staff during the using of the device. In addition, usually the basis for taking such decisions would be a personal opinion, or shallow understanding of the device and its implementation or poor information regarding life cycle cost. From this point view, the utilization of the LCC is a key factor to be a framework for making a wise decision related to suitable device purchasing. LCC would play a supportive element for the healthcare managers in motivating a strong evidence-based decision-making (Ison and Miller, 2000).

One other purpose of LCC is to help decision makers to select a medical device based on available alternatives in order to achieve the most economical option from inception to decommissioning. LCC takes into consideration the design, device selection, operation, maintenance and final disposition costs of a device over its lifespan.

In the short run, LCC approach can increase the department efficiency. However, the lower initial capital costs may be combined with high maintenance or operation costs over the device working years. LCC can help avoid unnecessary downtime and help make the medical device more profitable. At the very least, an LCC may prompt decision makers to consider a wider range of possibilities (Hoffmann and Abbe, 2013).

1.3 Definition of Medical Devices

Medical devices refer to "an instrument, apparatus, appliance, material or other article, whether used alone or in combination, together with any software necessary for its proper application, which is intended by the manufacturer to be used for the purposes of diagnosis, prevention, monitoring, treatment or alleviation of disease diagnosis, monitoring, treatment, alleviation of, or compensation for, an injury or physical impairment investigation, replacement or modification of the anatomy or of a physiological process control of conception" (Web site[1]).

A medical device does not achieve its principal intended action in or on the human body by pharmacological, immunological or metabolic means. This definition includes devices intended to administer a medicinal product, such as a syringe driver, or which incorporate a substance defined as a medicinal product, such as a drug-eluting stent (Bronzino, 2006).

1.4 Selection of Medical Devices

For any medical device to be selected and purchased in order to be used during clinical practice, it is important to meet specific performance specifications. Through the selection procedure more than one product will be available that is capable of performing the required function. Two general important factors to select one product over another:

1- The safety factor (including those of cross-infection) to patients and staff during the use of the device at the patient-care interface;

2- The cost of the device.

However, other factors are not normally taken into account during the selection and purchase of medical devices, such as: the scrapping costs, including treatment and final disposal costs of the device after use; the environmental effect of the device at the stages over its life (Ison and Miller, 2000).

1.5 Procedure of Medical Devices Purchasing at Ministry of Health (MOH), Jordan

In the Ministry of health (MOH), decisions regarding the medical devices purchases are usually performed by Medical Devices Directorate in

the Royal Scientific Association, Ministry of health and Government Tenders Department. Purchasing medical devices is performed by a staff that has a long standing experience with medical devices including engineers and clinical members who use the device.

In some cases when the medical devices are supplied using grants (funds), hospitals are provided by devices directly from suppliers/manufacturers. In this case, there may not be effective communication between the staff who provided devices and those who use them.

The users are an important part of the medical devices selection process because they can be very helpful in estimating the real needed specifications in the device. Figure 1.1 shows Management of device supplementations within Ministry of Health, Jordan.

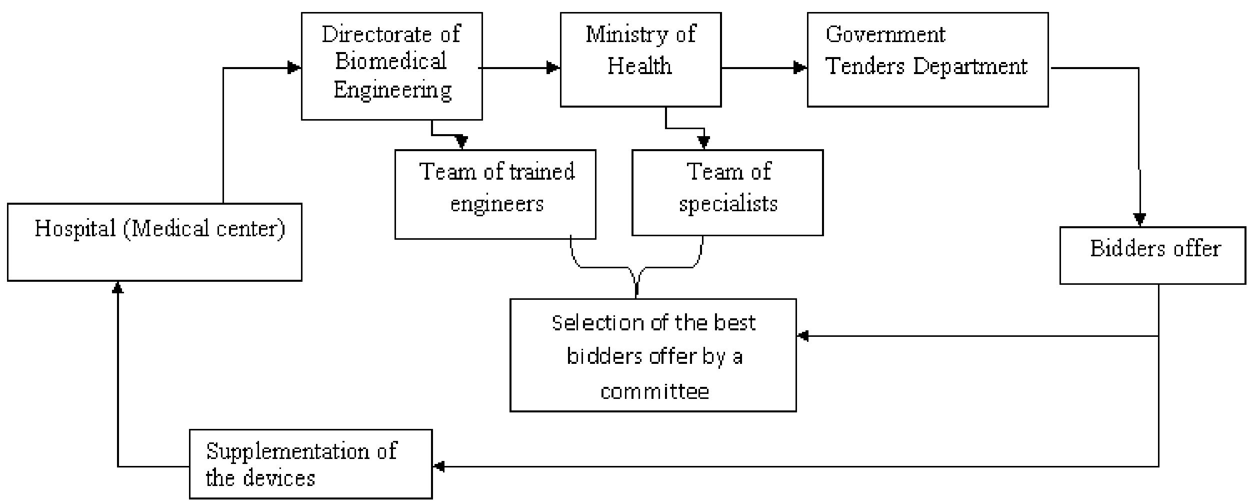


Figure 1.1
Management of device supplementations within Ministry of Health, Jordan

1.6 Objectives of Current Research

In general the objective of LCC analysis is to choose the most cost effective approach from a series of alternatives. So, the least long term cost of ownership is achieved while considering cost elements which include design, development, production, operation, maintenance, support, and final disposition of a major system over its anticipated useful life span (Bronzino, 1992).

When properly used (along with good engineering judgment), LCC provides a rich set of information for making cost effective, long term decisions in a disciplined manner .

This study was carried out to achieve the following objectives:

1. Estimating the LCC for medical devices which includes the device initial cost plus any other future related costs (maintenance, operation, supporting).
2. Estimating how and when sustaining costs occur during the life cycle of the device. Adding expected device failure rates and renewals from a statistical viewpoint makes analysis about economics smarter and gets the rational decisions closer to real conditions.
3. Helping in estimating the total cost of medical device ownership and knowing the future cost of choosing a certain device.
4. Helping the decision makers to monitor and control the evolution of ownership cost of a medical device.
5. Enhance the role of engineering management to help decision makers to select the most effective medical devices.

1.7 Importance of the Present Research

Since the role of the engineer is to suggest and recommend cost effective alternatives. Much lower LCC value is obtained when creative efforts are employed from the design phase over the all entire life of the device.

The LCC approach provides a complete overview about the total cost structure of a product in each phase of its individual lifetime. Thus, LCC will lead to the following advantage when its exploited in investment decisions (Barringer, 2003; Zimmermann, 2005) such as:

1- LCC is particularly useful for decisions that are too complex and ambiguous for experience and subjective judgment alone.
2- Application of LCC will help decision makers perceive and include costs that often are hidden or ignored during the purchase of medical devices, and that may otherwise lead to more costs should afforded during the life span of medical devices.
3- Application of LCC will facilitate the comparisons between the products could be obtained from different sources and consequently help the decision maker.
4- Encourage government tenders department to invest the concept of LCC during tenders evaluation process.
5- LCC is applicable to complex, high cost choices among alternative technologies, new service, and different means for providing a given service.

1.8 Methodology

The methodology going to be used in this study will focus on two alternatives (i.e. models) of particular medical devices with the same function but from different sources or models. Yearly LCC values will be the guide to make decision about the best alternative of the two available models.

Data required for LCC estimation for this study were collected from historical maintenance records, operators who operate and deal with the device and the technical engineers' experience.

Six devices from three different groups were taken in consideration in this study; these devices have been chosen according to their historical records (Table 1.1).

1.9 Study Site and the Application of LCC in the Healthcare Sector: a Case-Study Approach

Our study site is Al Karak Public Hospital, which has 370 beds and a suite of 7 operating theatres. The hospital was established in 1992 in an area of 13.2 hectare and total building area of 6500 m^2. The hospital contains hospital clinics with an area of 2950 m^2. The buildings are divided into sections (i.e., departments) as described in Table 1.

Table 1.1
The study cases devices and their models

Device	Model 1	Model 2	Function
Electrolyte	Easystate Plus Medica Corporation, USA.	AVL-9810, Roche, USA.	Measure the Na^+, K^+, Cl^-, Li^+, ions concentration in the blood serum.
X – ray	UD150L-30E SHIMADZU Corporation, Japan.	KXO-50R Toshiba, Jaban.	Generate X-rays, to acquire an highly penetrating images of the inside of the body, and is usually used in areas with a high bone content.
Infant incubator	Air shields C450 Vickers company PLC, UK.	Nestoret 5050 Guido Rayos X.SA, Spain.	To keep a baby’s core temperature stable at 37°. Most infant incubators also humidify the air and can add extra oxygen.

Table 1.2

Al Karak hospital departments and their capacity

Department	No. of Beds	Notes
Administration and Medical record department.	----	
Department of Emergency	36	1 miner operation room
Department of Internal Medicine (male)	60	President award is included
Department of Internal Medicine (female)	46	
Department of Obstetrics and Gynecology	70	1 operation room
Department of Intensive Care Unit	14	
Department of Chronic Care Unit	10	
Department of Pediatrics	55	
Department of Nursery children and premature	30	
Department of Dialysis	23	
Department of Physical Therapy	7	Male and Female
Department of Radiology	5	Preparation
Department of Operation	5	
Laboratory	-----	----

Chapter Two
Literature Review

A systematic review of the literature available on life cycle cost brought out that there are few research studies concerning the effect of the LCC on the decision making related to medical devices. As a key word “Life cycle cost” was used to search it in databases available in electronic library at Mutah University. In order to cover engineering and “Life cycle cost” related topics, electronic library data bases at Mutah University and search engines were used.

2.1 Definition of LCC:

Various definitions of the LCC were found in literature. According to the ISO standards, LCC can be defined as: The *life-cycle* of a medical device includes all phases from initial concept, design to production and post-production, includes final decommissioning and disposal (ISO 14971, 2007). This definition describes LCC as a technique of analysis needs to be considered at different points along the device life estimating all the significant costs of the device over its economic life.

In 1977, the UK Department of Industry published one of the earliest definitions of life-cycle costing as follows "A concept which brings together a number of techniques - engineering, accounting, mathematical and statistical to take account of all significant net expenditures arising during the ownership of an asset. Life-cycle costing is concerned with quantifying options to ascertain the optimum choice of asset configuration. It enables the total life-cycle cost and the tradeoff between cost elements, during the asset life phases to be studied and for their optimum selection use and replacement".

Similarly, in 1977, the American Institute of Architects defined LCC as follows: "A technique that allows the assessment of a given solution or choice among alternate solutions on the basis of considering all relevant economical consequences over a given time" (Boussabaine and Kirkham, 2004).

According to Lindholm & Suomala (2004), it's an economic examination that aims at showing a comprehensive estimation of the total costs of alternative devices or activities along the device life. It is usually possible to affect the future costs in advance by either planning the use of a device or by improving the device itself which is a basis for life cycle costing.

Buys, Bendewald, & Tupper, (2010) defines LCC as "a financial tool that uses discounted cash flows to evaluate a device given a set of constraints, which include time period and discount rate”. LCC is used as a tool to optimize the overall costs in the long run life of the device starting from the

design phase, through the operating and maintenance phases to the device obsolete phase (Lindholm & Suomala, 2004).

The LCC approach assists in the evaluation of different alternatives over the device estimated life time in order to achieve the lowest cost of product. This approach derives from the fact that any device contains of different subparts and passes through different milestones over its entire life span; each of these subparts has different choices which will directly affect the device LCC. By utilizing the LCC approach decision can be reached as to which offers the least cost in the life cycle (Lindholm and Suomala, 2004).

An empirical applicable advantage of the LCC is to monitor the device's performance in operation and get key information which will be the base of the future decisions. The focus of LCC changes during the device's life cycle. At the beginning of the device's life, LCC is about estimating any possible costs would appear at future. Over time, the focus of LCC changes to monitoring the occurred costs during the device operation, where the overall LCC statement will be clear at the end of the device life. Figure 2.1 shows the approach of the LCC for any device (Lindholm and Suomala, 2004).

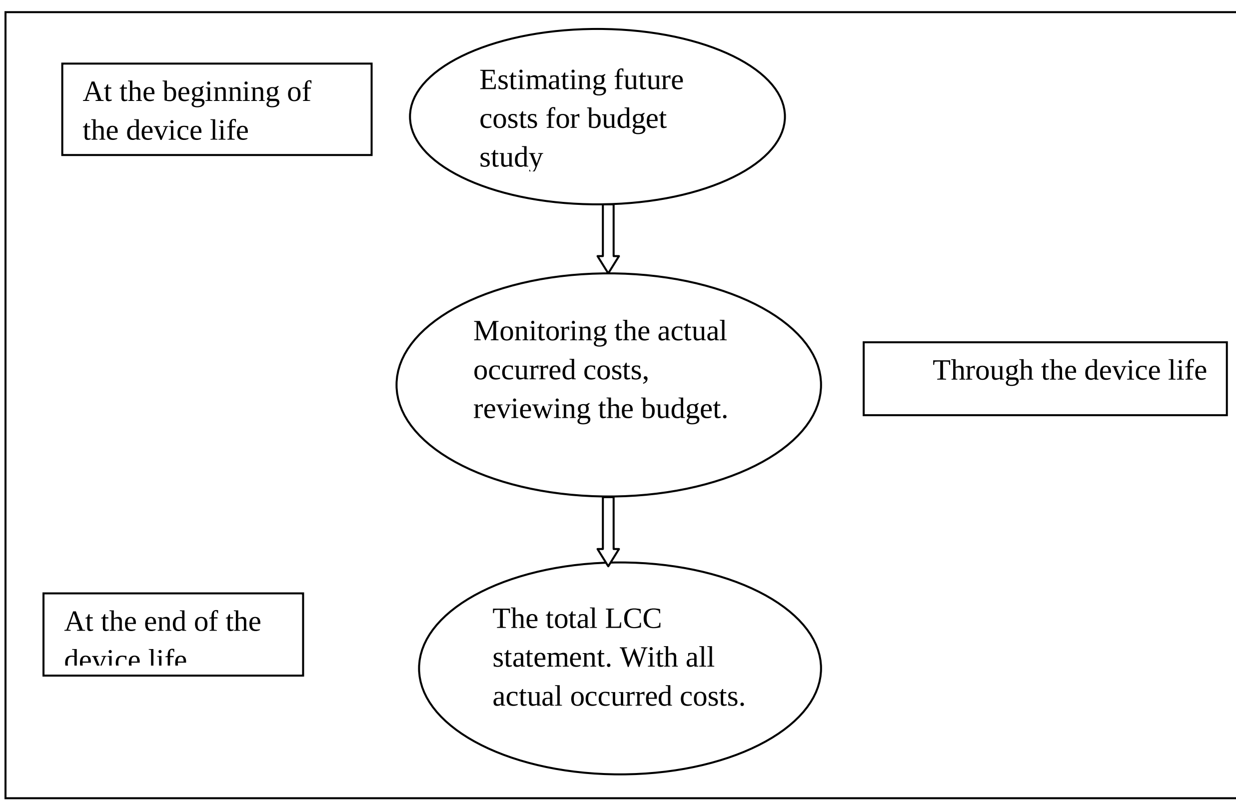


Figure 2.1
The changing focus of life cycle cost during a device's life cycle (Adopted from Lindholm & Suomala, 2004)

The life-cycle of any medical device can be divided into two phases: production phase and post-production phase. The production cost includes all initial costs of devices to be in service, whereas the ***post-production*** phase includes device installation (including; transportation and storage), the operation costs, the maintenance and repair of the device, the device modification, and the device disposal and any activity may sustain and support the device through it life. This phase starts after the design has been completed and the medical device has been manufactured (ISO 14971, 2007)**.**

2.2 History of LCC

The concept of Life-Cycle Cost (LCC) at the beginning has been used by the U.S. Department of Defense (DoD) in USA during World War II for weapons owners and systems that supports weapon. In the middle of 1960's, the DoD further developed the LCC theory in their procurements policies (Gluch and Baumann, 2004). To overcome the destruction of the World War II, Japanese invested the LCC concept which helped in their economy revival by saving costs in the long term (Gluch and Baumann, 2004).

The first civilian application of the LCC was in buildings to choose between the different energy designs alternatives in the late 1970's (Gautam, 2009). In that period the procurement decisions were depends on the capital cost, where a school of thoughts known as "Terotechnology" enhanced another way of making decisions rather than the capital cost only. Then the term cost-in-use appeared in the literature, which referred to as operational costs of assets. The weakness of the cost-in-use model was its inability to forecast future costs (Boussabaine and Kirkham, 2004). LCC became the bases for decision making, the way of selecting the best alternative available from different sources refers to the ability of the LCC in forecasting the future costs (Gautam, 2009).

The detailed history of LCC was reviewed by (Dhillon, 2010).The LCC of engineering system ownership could be defined as the sum of all costs included over the device life time or the total of acquisition and ownership costs. The LCC as a term was first used in 1965 in a report entitled “Life Cycle Costing in Equipment Procurement”. This report was published by the Logistics Management Institute, Washington, D.C. (Logistics Management Institute, 1965), for the assistant secretary of defense for installations and logistics, U.S. Department of Defense, Washington, D.C. As a result of this report, the Department of Defense published a series of three guidelines for life cycle costing procurement, entitled “Life Cycle Costing Procurement Guide (Interim),” “Life Cycle Costing in Equipment Procurement—Casebook,” and “Life Cycle Costing Guide for System Acquisitions (Interim)”.

In 1971, the Department of Defense issued Directive 5000.1 (Dhillon, 2010), entitled "Acquisition of Major Defense Systems," concerning the requirement for life cycle costing procurement for major systems acquisitions. In 1974, the concept of life cycle costing was formally adopted by the state of Florida and, in 1975, a project entitled "Life Cycle Budgeting and Costing as an Aid in Decision Making" was initiated by the United States Department of Health, Education, and Welfare. In 1978, the U.S. Congress passed the National Energy Conservation Policy Act, which made it mandatory for every new federal building to be life cycle cost effective. Since 1974, states such as New Mexico, Alaska, Maryland, North Carolina, and Texas have passed legislation that make life cycle cost analysis mandatory in the planning, design, and construction of all state buildings.

Two methods were emerged in the mid-1970s (Steen, 2005; Dhillon, 2010) : The major constrains in LCC is to find out the items should be included LCA developed more slowly. Initially, the focus was energy balances. Then, mass balances were added, including material and waste streams. Later, environmental assessments were made for the mass and energy balances, and the framework developed gradually. Since the early 1990s, there has significant development of LCA, both in terms of methodology and applications. The development of LCA methodology includes using softwares which make the analysis easier and faster, using various ISO standards which improved communication.

Nowadays, LCC became an important decision tool in many engineering systems due to huge world economy and due to diversification in the product sources. The selection of a device procurement should not only based on the most expensive device and/or the initial procurement cost, but also but rather on their LCCs. Previous experiences by pointed that often engineering system ownership costs exceed initial costs of the device. In fact, according to various studies, the engineering system ownership cost (i.e., logistic and operating cost) can vary from 10 to 100 times the initial purchasing cost (Dhillon, 2010).

2.3 Benefits and Advantages of Life Cycle Costing

Many benefits could be attained from implementation of life cycle costing in engineering systems including as summarized by previous studies (Dell'Isola and Kirk, 1995; Gluch and Baumann, 2004; Steen, 2005; Dhillon, 2008; Gautam, 2009).

- The life cycle concepts implement earlier actions that required generating the lowest costs scenarios that might be considered

- Helping decisions" makers to take the most suitable decision based on accurate and realistic assessment of revenues and costs of a device
- Promote the decision makers thinking for long term rewarding in contrast to short-term profitability rewarding
- The life cycle concept helps engineering system to understand the initial procurement cost *vs*. the costs during the device life span. It encourages decisions makers to find out the most profitable rewarding from a device by associating investment costs and operating expenses. With life cycle costing, non-production costs are traced to individual products over complete life cycles
- Over the device life span all the incurred costs can be reported and saved as a database for future research or development of the device. The LCC will open eyes on such costs
- The profits of any device can easily be understood by estimating all the contributed costs
- Obviously the information results from LCC will act a key feedback for the organizations that reflects the success or failure of any decision related the studied devices, and affect on the forward steps in developing new devices
- Useful in comparing the cost based on the whole life cycle cost rather than the initial cost of a device when selecting a device from different sources (i.e. different manufactures). It is an excellent tool for making a selection among the competing contractors/manufacturers

In order to optimize the management costs and to be strongly competing in marketing a device, manufactures, should continuously redesigning their devices to reduce their life cycle costing as much as they can. The planning, design and development stages of a device's cycle are the vital stages where the manufactures can reduce the life costing of that device rather than the operation cost through the service stages.

2.4 Life Cycle Costing Disadvantages and Related Important Points

Over the past decades, disadvantages of life cycle costing were recognized some of them were extracted from (Boussabaine and Kirkham, 2004; Gluch and Baumann, 2004; Gautam, 2009; Dhillon, 2010).

Some of the main disadvantages of life cycle costing include:

- It's time consuming and costly process, it requires summation of all possible incurred during the life span of the device. Moreover,

it requires huge effort to collect and analyze data required in LCC estimation

- It could be over- or under estimated due to data inaccuracy in estimating costs incurred during the life time of the device. Here, the source of inaccurate data could arise from the fact that many values used to calculate LCC came from personal estimation of the device operators and/ or the persons performing the LCC analysis, which could be vary from one person to another
- It is a forecasting approach. Consequently it needs professional experience to deal with hidden factors affecting LCC estimation

The long term goal of life cycle costing is to obtain the maximum benefit from deficient resources. Consequently, many important points should be taken into account during the estimation process of the life cycle costing, including (Gluch and Baumann, 2004; Dhillon, 2008; Gautam, 2009):

- Organization management in implementing LCC results, which makes LCC a worthwhile effort
- Since LCC is a forecasting process, some surprises may arise with LCC estimation even when the estimator is very competent, the risk resulted from such factors should be taken into consideration during LCC estimation process
- The accuracy of the available data is vital for good life cycle cost estimates
- Using a life cycle cost model has to include all costs incurred during the model programming
- There is a need to get a balance between the device manufacturer who aims at reducing of the planning, designing and manufacturing costs and the user demand to minimize the operating cost. This will efficiently control life cycle cost of a device

2.5 Typical Applications of Life Cycle Costing

Reducing and/or controlling the costs over the device life span is a key objective of life cycle costing by evaluating the financial effect of the decisions taken over the device whole life. Related to this main objective, life cycle costing can be applied in different areas such as (NATO Science and Technology organization, 2007; Dhillon, 2010):

- Selecting between the competing bidders for a device
- Planning and distributing the expenditures over the device whole life
- Controlling a device needed costs through its service life

- Comparing competing alternatives, and scenarios; i.e. deciding the replacement of aging equipment
- Comparing logistics concepts

The three main areas of applying LCC are (NATO Science and Technology organization, 2007):

a. Forecasting of future expenditure: In many cases the decision makers are facing choosing between different competing alternatives, the LCC helps decision makers and planners by addressing key questions in consideration of long term planning (more 10 years) or short term planning (1- 4 years)
   - What will be the cost of the systems (devices) currently being designed in future in terms of all the costs initiated along its service life?
   - What is the best ratio between money spent on investment in new systems to that spent in keeping the readiness of currently available systems (devices)?
   - How many systems (devices) can be afforded (now) with maintaining some flexibility in future budgets (considering their estimated in-service costs)?

b. Examining comparisons between alternative solutions, or scenarios

c. Supporting the tender evaluation process

In the all planning stages the comparative study are valuable and important to take the best economical available choices and actions. By studying all different alternatives many elements will be tested like technical risk, design maturity and cost. This will be valuable for the decision makers in following ways:

- Clarify the advantages and disadvantages, the risk, and the uncertainty of the studied alternatives. Study the sensitivity to any possible changes for each alternative.
- Help decision makers to determine which one of the proposed alternatives offers the most sufficient benefits in terms of operation or/ and economic, and which one worth the cost. The preferable alternative will be the alternative with the best ratio of its benefits to its cost.
- Supporting the competing bidder's evaluation process.

In the tender evaluation process the LCC is used to ensure that the contract award is made to the bidder who meets the all requirements and offers the minimum LCC. The LCC in the evaluation process often used as a baseline for negotiation on contractor logistic support contracts.

The LCC analysis in tenders evaluating process should consider the reducing costs in the maintenance procedures and the all costs that support and operate the system (device) over the life time against the cost of overall investment. The estimation of the in service system (device) in the LCC for the tender evaluation must be considered precisely and fit its purpose (NATO Science and Technology organization, 2007). Frequently the total life time of a system (device) mayn't be the suitable period of time for LCC evaluation. Evaluation of LCC in a short period of time focuses on the initial acquisition costs, whereas for longer period of time focuses on the recurrent ownership costs.

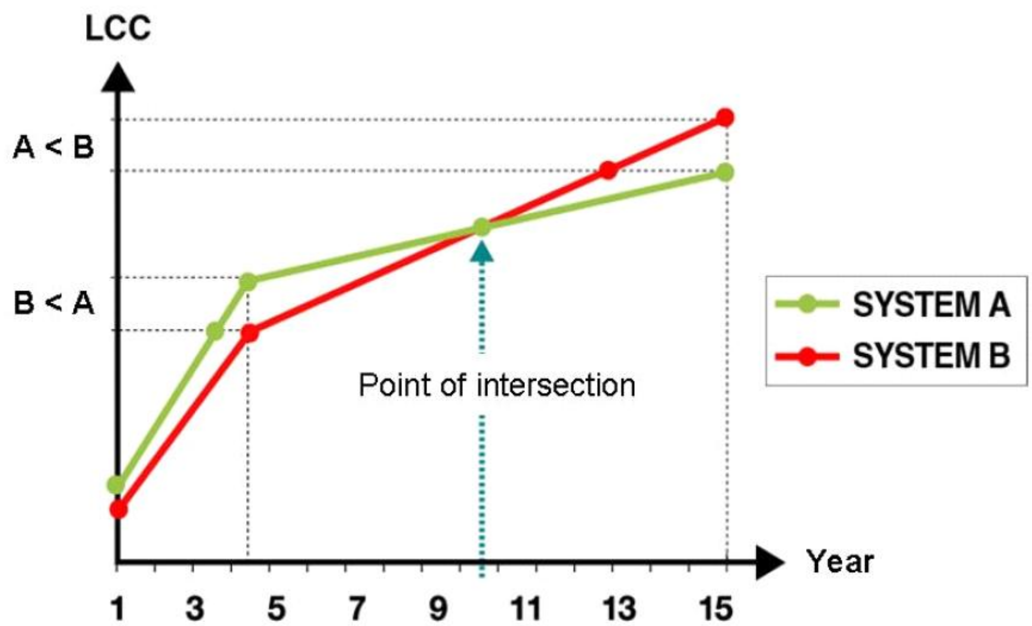


Figure 2.2

Presents the life cycle costs for two competing systems A (gray) and B (black) (Source: NATO Science and Technology organization, 2007).

Figure 2.2 shows the selecting of the "correct" time period is complicated in order to be included in a tender evaluation. The initial acquisition price for system B is less than system A. However, system A has lower annual cost for ownership than System B. At two different time periods year 10 and year 5, the cost-lines intersect at year 10, where after year 10 system A LCC is lower than system B.

Lamar (1981) as cited in Dhillon (2010) listed more specific applications of LCC including:

- Determining cost drivers
- Forecasting future budget needs
- Selecting the most effective procurement strategy
- Improving comprehension of fundamental design-related parameters in device or system product design and development

- Formulating contractor incentives
- Making strategic decisions and design trade-offs
- Optimizing appropriate training needs
- Choosing among options
- Providing effective objectives for program control
- Assessing new technology application
- Carrying out source selections.

2.6 Decision Making and LCC

In all cases, the output of the LCC provides information to support the decision making process. However, the cost is just one of many criteria that could influence the decision. Other criteria such as operational effectiveness, technical risk, political and industrial policy constraints, etc., also have to be considered in the decision making process and are sometimes more important than cost (NATO Science and Technology organization, 2007).

LCC is increasingly being used in the industrial sector around the world to make various types of decisions that directly or indirectly concern engineering equipment and systems. The state-of-practice, tools, methodologies, and techniques vary widely depending on the particular area of life cycle concerns (Allouche and Freure, 2002; Salem et al., 2003).

LCC analysis helps in decision-making process to select the most cost-effective alternative for the maintenance and renewal of devices. “The aim of the decision-making process is to identify the Applied actions that will most benefit the engineering system’s state and performance within pre-determined economical, time, and resource constraints" (Allouche and Freure, 2002).

Returns of investment in devices are important in making decisions on investment scenarios. For this topic a combination of knowledge about the investment, and skills for analysis and elicitation of decisions from the available information, the experience of the decision makers and judgments (Boussabaine and Kirkham, 2004).

2.7 Cost Components of LCC

Frequently the cost of sustaining devices is 2 to 20 times the acquisition cost (Barringer et al., 1997). An LCC may include the costs for acquisition and the costs for sustaining the acquisition during its life which are initial, operating, maintenance, service, remodeling, and end-of-life costs. The cost components were summarized using the standard procedures used in previous studies (Asiedu & Gu, 1998; H.P. Barringer et al., 1997; Boussabaine & Kirkham, 2004; Illinois & Board, 1991; Reidy et al., 2005; Woodward, 1997).

2.7.1 Initial Capital Costs

The initial capital costs include three cost subcategories:

- Purchase costs
- Acquisition /finance costs
- Installation and training costs

The acquisition costs includes the overall costs of purchasing a device which is estimated by suppliers and agents; and the all development and implementation costs that required to make that device operate. Finance costs include the cost effect of investing in another alternative source. The other costs include the costs of installing the machine and the costs of training workers to operate it. In general, the capital cost refers all the costs of buying a device and bringing it into operation.

2.7.2 Operation Cost

LCC is all about operating any devices to minimum cost. Operating cost includes:

- Direct labour cost
- Direct materials cost
- Establishment costs cost
- Energy consumption cost

The estimation of these costs is based on both expected and actual experience of the performance of similar devices. For fixed costs through the device life time, the annual cost can be calculated by multiplying these costs with a discount factor.

2.7.3 Maintenance Costs

Maintenance refers to the costs incurred to keep devices running properly. The wide array of activities performed for maintenance engineering and technician fall into four cost categories: preventive, corrective, predictive, and planned, maintenance. These can be estimated from historical data provided by maintenance reports. Maintenance costs include direct labour, materials, electrical power, and spare parts purchased services.

Maintenance costs can normally be broken down into smaller classifications such as:

- Regular planned maintenance, preventive maintenance
- Unplanned maintenance (responding to faults) corrective maintenance
- Predictive Maintenance (Inspecting for failures)
- Intermittent maintenance (for major life refurbishment);

The organization's objective of attaining minimum total cost can be performed through a cumulative relation between the different types of maintenance (Sullivan et al., 2002).

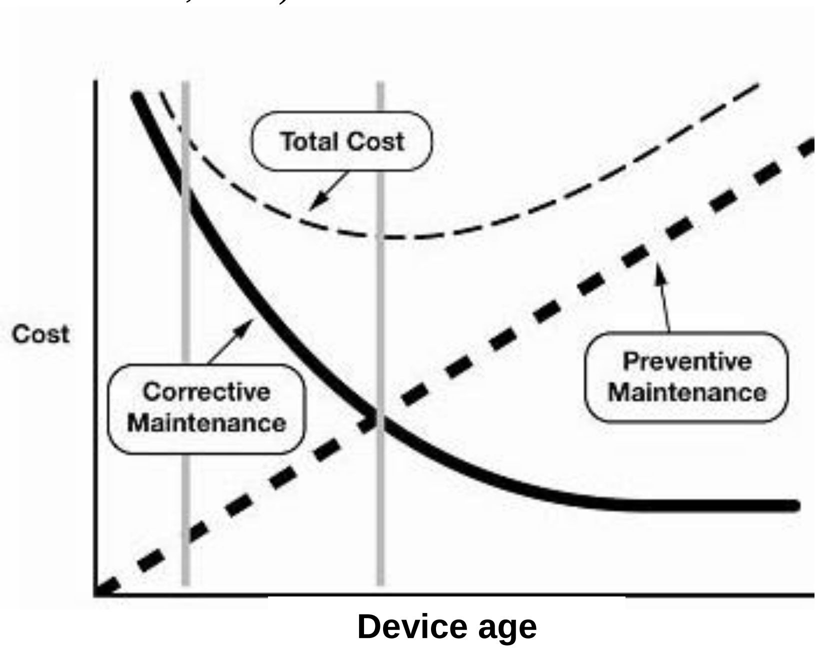


Figure 2.3
Cost–different maintenance type's relationship Source (Web site [2])

Figure 2.3 shows the total cost spread with intersection of Corrective Maintenance and Preventative Costs indicating the Total Cost desired low point.

In addition to the different types of maintenance cost the man-hour cost and the spare part cost should be included in LCC calculations where,

- Man-hour Cost is the total maintenance man-hour cost required to maintain the device within the different type of required maintenance.
- Spare Part Cost is the total cost of spare parts, over the design life of the device, necessary to complete any maintenance actions (i.e. preventive maintenance, corrective maintenance and servicing) (Norsok Standard, 1996).

a) Preventive Maintenance

Preventive maintenance is a routine, scheduled activity intended to keep a device running at its best. The periodic preventive maintenance philosophy is to prevent breakdowns to reduce the downtimes costs, by performing it whether or not there are any problems with the device.

The key factor is to find an optimal level of maintenance service in order to be consistent with the organization's objective of attaining minimum

total cost. Preventive maintenance costs associated with devices and systems should be incorporated into LCC analysis calculations (Norsok Standard, 1996)

b) Corrective maintenance

Corrective maintenance philosophy is 'run it until it breaks' it is a response to any problems in the device. This approach reduces the maintenance expenditures but increases the downtime loss. Corrective maintenance is unpredictable since failures are unplanned and need to be repaired. In theory, if systems are running well and all required preventive maintenance is performed, then corrective maintenance should be minimal (Norsok Standard, 1996; Edward et al., 2000)

c) Predictive (Inspecting) Maintenance

Predictive maintenance (PdM) is a technique determines the condition of in-service devices to predict when maintenance should be performed. The main objective of Predicted Maintenance is to find out "the right information in the right time" which allows to plane and schedule the corrective maintenance for the founded failures.

Performing this technique saves costs by reducing the unexpected equipment failures. Other potential advantages include increasing device lifetime, assuring safety usage of the devices, and optimizing spare parts handling, through monitoring the device performance while it works and evaluating its conditions (Norsok Standard, 1996; Edward et al., 2000).

d) Planned Maintenance

Planned maintenance refers to the replacement of certain parts of the device that aren't included in the preventive maintenance procedure at the end of their estimated life. LCC calculations expressly include planned maintenance in the form of replacement costs of systems at the estimated life of the replaced parts.

For any organization the key factor is to obtain an optimal level of maintenance service with minimum cost this can be achieved by replacing such parts that increase the downtime costs if they wear out before replacing them (Norsok Standard, 1996; Edward et al., 2000).

2.7.4 Residual Value, Salvage Value, Disposal Cost

This is the cost incurred at the end of a device's service life in disposing of it. The disposal cost may include the cost of, scrapping or selling, or giving away (as a grand) the device. This estimated scrap value at the end of the useful life of a device also called the residual value of that device (Norsok Standard, 1996; Edward et al., 2000).

2.8 **LCC Procedure**

The general procedure for LCC analysis was created by Harvey in the middle of the 1970th as cited in (Woodward, 1997); this procedure includes four steps to find LCC. These steps are shown in Figure 2.4and listed below:

1. The cost elements of interest
   This step defining all the costs consists from acquisition to disposal at the end of its life. In this step costs are grouped to introduce trade- offs.
2. Defining the cost structure
   This consists of grouping costs thereby to achieve optimum LCC. The cost structure depends on the required and the objective of the LCC study. Also the available alternatives may affect on the structure.
   Harvey concluded that, "The important point is that the structure must be designed so that the analyst can perform the necessary LCC analysis and 'trade-offs' to suit the objectives of the project and the company concerned."
3. A cost estimating relationship (The developed condition of cost categorize)
   A cost estimating relationship is "a mathematical expression that describes, for estimating purposes, the cost of an item or activity as a function of one or more independent variables".
4. Establishing the method of LCC formulation;
   In this step the methodology is defined in order to find the needed LCC(Woodward, 1997).

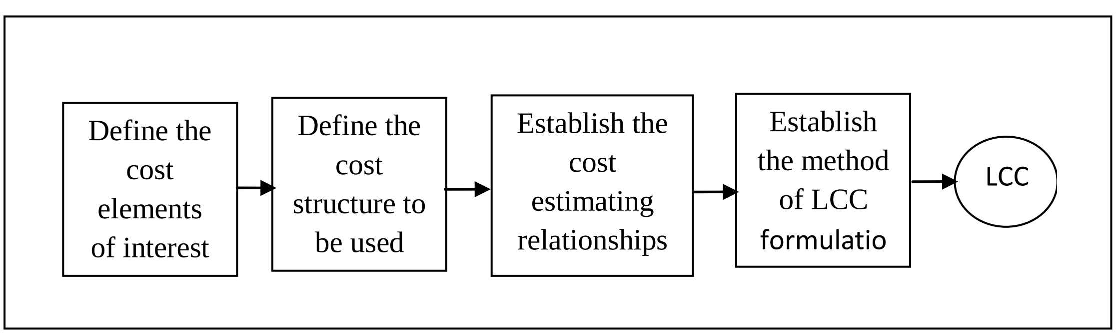


Figure 2.4
The general LCC procedure which was prepared by Harvey's

Kaufman has developed a comprehensive approach of eight steps for LCC analysis these steps are:

1- To define operating profile. Which describes the periodic cycle and contains the modes of start up, operating and shut down, so it indicates to the proportion of time the device will be operating or not operating?

2- To establish of the utilization factors indicated in what way equipment will be functioning, the working fraction of any device. Thus, even within the 'operating' mode, a machine might not be working continuously

3- Identifying all the cost elements (i.e. initial cost, operation cost et al.).

4- Identifying the most critical cost parameters which control the degree of the costs incurred during the life of the device. The most significant of these are:

- Time period between failures (Kaufman's 'MTBF')
- Time period to repairs (Kaufman's 'MTTR')
- Time period for scheduled maintenance
- Energy use rate

5- All costs should be calculated at current rates.

6- Kaufman procedure calculates the current costs at assumed inflation rates.

7- To discount back all costs to the base period. It is known that money which has a time value and the cash flows developing in different time periods are discounted back to the main period to warrant equitability.

8- Reach LCC summing the discounted costs to establish the net present value (Woodward, 1997).

The figure below shows the comprehensive Kaufman approach with its eight steps and all the possible costs (Woodward, 1997).

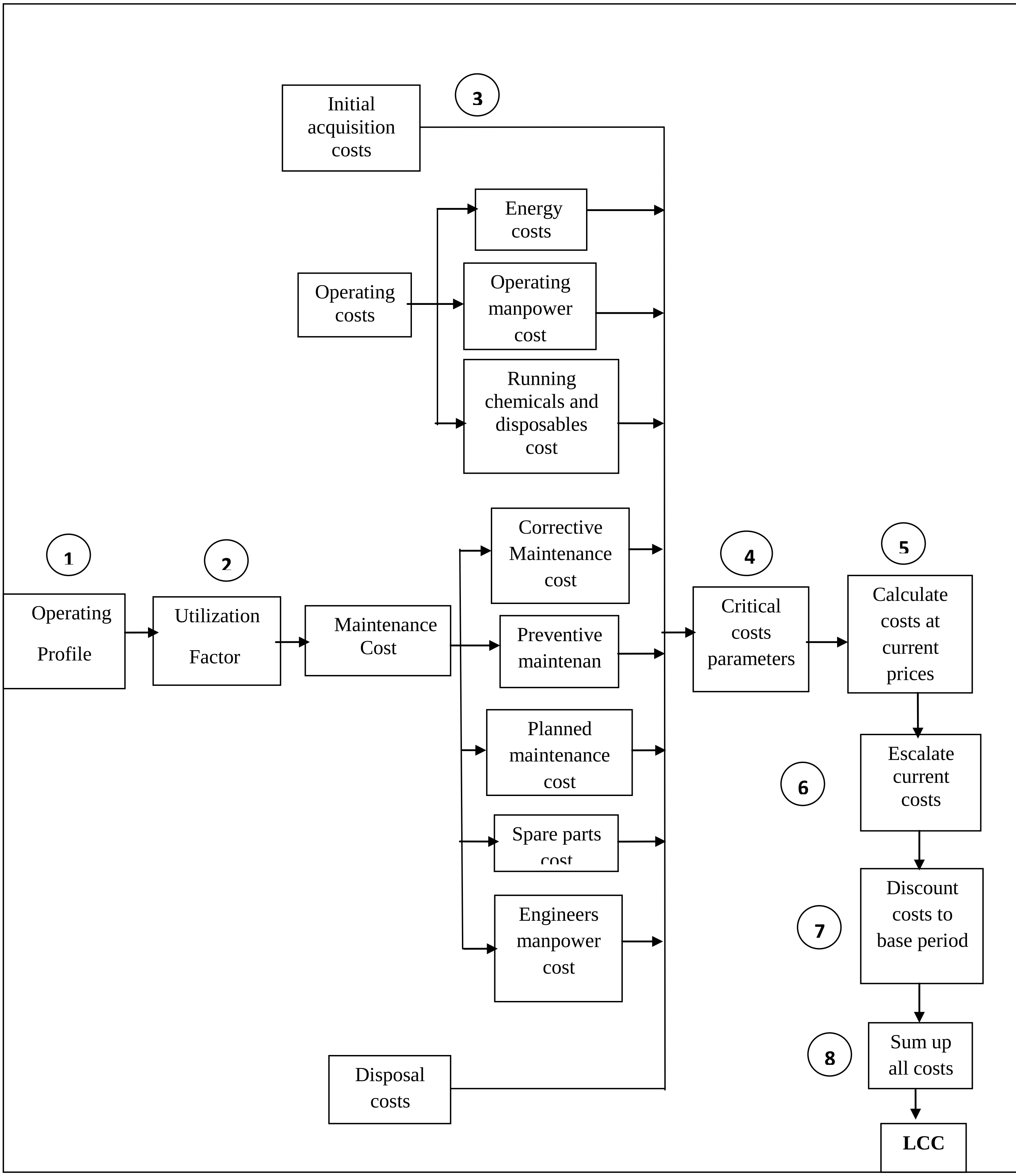


Figure 2.5

Life cycle costing formulation adopted from Kaufman's life cycle costing formulation (Woodward, 1997)

2.9 Calculating Life Cycle Costs

This section explains fundamental concepts behind LCC (Illinois and Board, 1991; Woodward, 1997; Asiedu and Gu, 1998; Reidy et al., 2005).

2.9.1 Fundamental Concepts

A number of basic concepts underlie LCC as seen in different articles and books should be taken in consideration as they have a great influence in the LCC calculation and very important in generating the LCC model including (Illinois and Board, 1991; Woodward, 1997; Boussabaine and Kirkham, 2004; Reidy et al., 2005).

a) **Time Value of Money**

The value of money today doesn't equal the value of money in future. This concept is referred to as the "time value of money" (Hazlitt, 1965).
The time value of money comes out from two factors:

1- Inflation, substantial rise in the general level of prices related to an increase in the volume of money and resulting in the loss of value of currency

2- Opportunity cost; which is the value of the best unselected alternative, in a situation in which a choice needs to be made between several alternatives given limited resources, it is the value of the second better alternative (Reidy et al., 2005).

b) Inflation

"A substantial rise of prices caused by an undue expansion in paper money or bank credit" (Hazlitt, 1965; Panneerselvam, 2012).

As a result of the rise in the cost of goods and services due to economic activity the value or purchasing power of money over time will be decreased. All costs need to be projected forward at appropriate rates of inflation. Inflation rates estimation should be very close to the real rates where any under estimating values may affect the final calculations (Woodward, 1997).

The Inflation Rate can be avoided or eliminated from LCC calculations, through using another approach was developed by Fisher, this approach discounts the real rate of interest, instead of the money rate.

Fisher approach defined as:

$$r_{money} = (1 + r_{real})(1 + i) - 1 \qquad (2.1)$$

Where, r = the rate of interest, and i = the rate of inflation (Fisher, 1961; Panneerselvam, 2012).

c) Discount Rate (Opportunity cost)

The discount rate is defined in terms of opportunity cost which is the minimum acceptable rate of return on an investment, all of the life cycle costs

must be discounted back to their present value through the appropriate equations (Dhillon, 2010).

The basic discount equation is as follows:

$$P_V = \frac{F_V}{(1+k)^t} \tag{2.2}$$

Where:
P_V = the present value in year 0)
F_V = the future value (in Year t)
k = the discount rate
t = the number of years in the future.

d) Escalation

Most devices prices don't change at exactly the same rate as inflation. The escalation rates as the discount rates were adjusted to eliminate the inflation effects; the escalation rate is essentially the same as the inflation rate, since the real escalation rate is close to zero or zero (Reidy et al., 2005).

The formula for calculating the future cost of an item with a known cost today and a known escalation rate is:

$$Cost_{t-t^\circ} = Cost_{t-0}(1+E)^{t^\circ} \tag{2.3}$$

Where :
$Cost_{t-t^\circ}$: The cost at t year into the future
$Cost_{t-0}$: Today's cost (at Year 0)
E: The escalation rate
t° : The number of years into the future.

2.9.2 Life of the asset

The expected life of any device has a major influence on the LCC especially with the exponential nature of the effect of this variable.

Ferry and Flanagan expected five possible types of a device's life (as cited in (Woodward, 1997):

- Functional life : the period over which the need for the asset is anticipated
- Physical life: the period over which the asset may be expected to last physically to when replacement or major rehabilitation is physically required
- Technological life: the period until technical obsolescence dictates replacement due to the development of a technologically superior alternative

- Economic life: the period until economic obsolescence dictates replacement with a lower cost alternative.
- Social and legal life: the period until human desire or legal requirement dictates replacement.

2.10 Life Cycle Cost Models and Cost Estimation Methods

Over the years, a large number of life cycle cost models have been created for general or specific systems; there is not a standard model because the different types of systems, devices, and equipments, the nature of problem, different cost data collection systems. The main objective of any model regardless to its type is how close this model represents the device or any system, to be implemented in LCC (Levander et al., 2014).

2.10.1 Life Cycle Cost Models

Calculation models take place in LCC implementation, which is used to forecast the characteristics of simple and complex systems, the type of this model depends on the nature of the system itself (Asiedu and Gu, 1998) .

These models are structured in different general categories:

- **Financial Models**

  Shupe and Brown adopted this model in LCC; (as cited in (Parker, 1991).This model uses a method bases on the discount rate, such as the annual worth method, benefit/cost method, return-on-investment method and present worth method, in order to compare all alternatives, and then select the best economic one(Parker, 1991)
- **Analytical Model**

  The analytical model bases on mathematical relationships modified to represent a specific system (device), which aims to reach the optimal point which is the minimum LCC and the maximum effectiveness of the studied system (device), (Dhillon, 2010).
- **Heuristic Model**

  However the heuristic models are specified for a certain under consideration system (device),but these models represent solution mayn't be the optimal one, and can't be used for wide range of systems(devices) (NATO Science and Technology organization, 2007; Kaya, 2009).
- **Conceptual Model**

  This model bases on hypothesized relationship between flexible variables expressed in a qualitative framework, this model can accommodate many systems; the conceptual models are quite flexible but have rather limited applications (Dhillon, 2010).

- **Parametric Model**

  Parametric models base on regression analysis in which historical data of cost experience and performance level of past similar systems provides a baseline for the future costs estimation providing a forecasting approach to compare a new system (device) with an exciting old one. This model helps in a rapid LCC for the interested systems (devices) to select the most cost effective alternative (Parker, 1991).

- **Accounting Model**

  This model uses detailed algorithms to directly relate design decisions to their effects on cost, some of these design decisions; part quality, redundancy, reliability, and maintenance concepts, which can be taken into account by the engineer. Accounting models are concerned with deep details than parametric models .This detail involves both the financial planning aspect and the cost optimization of the selected alternative (Parker, 1991).

- **Phased Models**

  Include both a two phase model and a four phase model. The two phase model is partitioned into acquisition costs and sustaining costs .The four phases are the research and development phase, the production phase, the maintenance phase, and the retirement and disposal phase (Parker, 1991).

Dhillon (2010) has divided the models in two major categories:

a) General life cycle cost models

b) Specific life-cycle cost models

a) General Lifecycle Cost Models:

General Life-cycle Cost Model I:

The U.S. Navy has developed this model for their weapon system; which consists of five cost components as follows:

$$LCC = RDC + OSC + ASC + IC + TC \qquad (2.4)$$

Where,

LCC = the life-cycle cost

RDC = the research and development cost

OSC = the operation and support cost

ASC = the associated system cost

IC = the investment cost, and

TC = the termination (Disposal) cost.

General Life-cycle Cost Model II:

According to the ASTM E917-89 (Kabbani, 1993), as cited in (Gautam, 2009), the model was expressed algebraically as:

$$PVL_{cc} = \sum_{t=0}^{N} \frac{C_t}{(1+i)^t} \quad (2.5)$$

Where,
PVLCC = the life-cycle cost expressed in Present-Value
Ct = the sum of all relevant costs occurring in year t
N = the length of study period, years, and
i = the discount rate

General Life-cycle Cost Model III:

The model discussed by Locks (1978) (as cited in (Dhillon, 2010) has three major components, namely procurement cost, initial logistic cost, and recurring cost. This model does not consider disposal costs.

$$LCC = PC + ILC + RC \quad (2.6)$$

Where,
LCC = the life-cycle cost
PC = the procurement cost
ILC = the initial logistic cost
RC = the recurring cost

General Life-cycle Cost Model IV:

This model was developed by the U.S. Army (Dhillon, 2010) is made up of three major components, including investment cost (IC), research and development cost (RDC), and operating and support cost (OSC). This model does not consider termination costs.

$$LCC = IC + \mathrm{RDC} + \mathrm{OSC} \quad (2.7)$$

Where,
IC, RDC and OSC as described before.

The investment cost contains transportation, production, cost of data, initial training, non-recurring investment costs, spare parts, system test, and evaluation, site operation, engineering cost, project management cost, and any other investment costs. Also, operation and support cost is consists of indirect support operation cost, consumption cost, depot maintenance cost, personnel cost, material modifications, and other direct support costs.

General Life-cycle Cost Model V:

In 1976 Dickinson developed a model concerning life-cycle cost of systems using four major components, failure cost (FLC), operating cost (OPC), and the initial cost (ITLC). This model also does not consider the disposal cost as follows:

$$LCC = FLC + \text{OPC} + \text{ITLC} \qquad (2.8)$$

The cost of average failure (CAF) can be estimated by this expression (Dixon & Anderson, 1976 as cited in Gautam, 2009):

$$CAF = PC + NRC + SOC + RC \qquad (2.9)$$

Where,

PC = the cost of parts,

NRC = the non-redundancy cost, the losses incurred by not incorporating redundancy in the devices or in the system,

SOC = the cost of stock out, and

RC = the repair cost.

General Life-cycle Cost Model VI:

Blanchard 1978(cited in(Gautam, 2009) proposed a life-cycle cost model with four major components, namely, research and development cost (RDC), production and construction cost (PCC), operation and support cost (OSC), and retirement and disposal cost (RADC):

$$LCC = RDC + PCC + OSC + RADC \qquad (2.\ 10)$$

Where,

RDC = the sum of planning, design, test and evaluation, research, software development and management costs;

PCC = the component of the production and construction cost, which includes manufacturing, quality control, construction, engineering, production analysis and production support;

SOC = the cost component of system/product distribution, sustaining logistic support, system/product operations;

RADC = the cost component for ultimate retirement cost, reclamation value, cost of disposal, and unscheduled maintenance actions.

b) Specific Life-cycle Cost Models:

Specific Life-cycle Cost Model - Fleet of Aircraft

This specific model was developed for estimating retrofitting a system of avionics for aircrafts fleets (Andrew, 1974; and Regulinski, T. L. and Gupta, 1983 as mentioned in (Gautam, 2009 Dhillon, 2010;) as shown below:

$$LCC = \left[\sum_{j=1}^{k}(CSRj + CMj)\right] + CHP + RFC \qquad (2.\ 11)$$

Where,

LCC = the life-cycle cost

CSRj = the cost associated with spares replacement for operational year j

CMj = the cost associated with maintenance for operational / year

k = the number of years

CHP = the hardware procurement cost

RFC = the retrofit cost made up of cost for inspection, installation, engineering, testing and drafting

Specific Life-cycle Cost Model - Electric Motors

This specific model was developed for estimating life-cycle cost of electric motors (Ganapathy, 1983 as cited in Gautam, 2009; Dhillon, 2010); which is given below:

$$LCC = MAC + MOC \tag{2. 12}$$

Where,

LCC = the life-cycle cost

MAC = the acquisition cost of the motor, and

MOC = the operating cost of the motor

This model assumes that the motor maintenance cost is negligible, and the present worth of operating cost *{MOC f)* for each yearly was calculated by:

$$PWj = MOC_j \left[\frac{1}{1 + \mathrm{i}}\right]^j \tag{2. 13 }$$

Where,

PWj = the present worth of MOC j

i = the interest rate, fraction

If the operational life of the motor was n years, the total present worth (TPW) of the operating cost can be given by the following equation:

$$TPW = MOC_1 \left[\frac{1}{1+i}\right]^1 + MOC_2 \left[\frac{1}{1+i}\right]^2 + MOC_3 \left[\frac{1}{1+i}\right]^3 + \cdots + MOC_n \left[\frac{1}{1+i}\right]^n \tag{2. 14 }$$

Where,

MOC j = the motor operating cost in year j = *1, 2,3, ..., n.*

For further analysis it was assumed that, in constant currency, the operating cost does not vary much during the operational life of the device, yielding:

MOC = MOCx = MOC 2 = MOC3 = ••• = MOCj

However, this model applies an escalation factor (ESF) in order to adjust the price escalation during the operational life of the device and thus equation (2.13) was rewritten as:

$$TPW = MOC\left[\left(\frac{1+ \ ESF}{1+i}\right)^{1} + \left(\frac{1+ \ ESF}{1+i}\right)^{2} + \left(\frac{1+ \ ESF}{1+i}\right)^{3} + \dots . + \left(\frac{1+ \ ESF}{1+i}\right)^{n}\right] \quad (2.\ 15\ )$$

Specific Life-cycle Cost Model – Car

Bhuyan (1982) developed this model for estimating life-cycle cost of acar (Gautam, 2009; Dhillon, 2010), and the life-cycle cost was defined as:

$$LCCc = ACc + \sum_{i=1}^{NL}(SMC_i + 0C_{\,i} + URC_i) + DC \quad (2.\ 16\ )$$

Where,

LCCc =the life-cycle cost of the car

ACC = the acquisition cost of the car

NL = the life time of the car in years

SMCi = the scheduled maintenance cost (tune up, lubrication, etc) of the car for year i; i = 1,2,3, ..., NL.

OCi = the operating cost (tire, gas, oil, etc) of the car for year /; i = 1, 2, 3,..., NL.

URCi = the scheduled repair cost (dependant on the failure rate of the model) of the car for year i; i = 1, 2, 3, ..., NL.

DC = the disposal plus any other cost (if any)

Specific Life-cycle Cost Model - Healthcare Facility

This specific model was applied in estimating life-cycle cost of a healthcare facility (Eddins-Earls,1981 as sited in (Gautam, 2009; Dhillon, 2010)and it was written as:

$$LCCHCF = CC + OC \quad (2.\ 17\ )$$

Where,

LCCHCF = the life-cycle cost of healthcare facility

CC =the capital cost, made up of costs such as financing cost, indirect cost, denial of use cost, land acquisition cost, direct construction

or purchase cost, collateral equipment cost, alteration and replacement cost, demolition and site preparation cost

OC = the operating cost, consisting of costs such as utilities and fuel costs, device(furnishing) and maintenance costs, structural maintenance costs, heating system costs, cleaning costs, restoration costs, fire protection costs, painting costs, incinerator and trash removal, air conditioning and ventilation system operation and maintenance cost, plumbing and sewer cost, electrical system operation and repair cost.

Generally, the following cost model is commonly used in the LCC calculation:

$$LCC = C + M + R - S \qquad (2.18)$$

Where,

C = the capital/investment cost, M = the operation and maintenance cost
R = the repair and replacement/alteration cost and S = the salvage value.

2.10.2 Types of Life Cycle Cost Methods

Many of cost estimation methods or approaches have been developed to be applicable and effective with different applications. Cost estimation is an important activity and should be close to the actual value since any estimation mistake leads to serious consequences. Each method has its advantages and disadvantages. This simply means that extra care is necessary in selecting a cost estimation method for a specific application(Parker, 1991; Asiedu and Gu, 1998; Dhillon, 2010).

LCC methods play major role in its calculation. By utilizing these methods, the whole cost can be projected and a decision reached as to which offers the least cost in the life cycle. For doing this, one of the basic attributes of the LCC technique is discounting where all costs are transferred to common point in time allowing comparisons between different design solutions to be made.

Kayas (2009) reviewed the most commonly preferred methods of LCC which are:

a) Historical LCC methods are:

- **Present worth cost approach**,

The present worth cost approach (PWC) allows for a more detailed evaluation of future costs. The present worth method uses the discount rate to convert future expenditures for each alternative to their equivalent present values, and then compares the present worth of each alternative(Parker, 1991)

When using this method, effects of two factors should be ignored. One is the inflation rate which defines future costs and the other is the interest rate which determines the present value of the future costs (Kaya, 2009).

The PWC method without considering inflation is calculated by using this equation:

$$P = F \frac{1}{(1+i)^n} \qquad (2.19)$$

This equation applies when inflation is taken into account:

$$P = F \frac{(1+f)^n}{(1+i)^n} = F \left[\frac{1+f}{1+i}\right]^n \qquad (2.20)$$

If the present value of equal payment at the end of 'n' years is calculated (without inflation), the equation is:

$$P = A \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \qquad (2.21)$$

- **Equivalence annual cost approach,**

The annual worth method uses the discount rate to convert the cash flow from each alternative into equivalent uniform annual amounts, and then compares each amount. The best economic choice is the one with the greatest equivalent annual worth(Parker, 1991).

This approach results are more easily to be understood to be used in decisions making. Moreover, it is clearer to be computed than the PWC method in the case of a regular annual series of payments. Therefore, the EUAC represents the summation of the annual capital cost and the annual operating cost (Kaya, 2009). Its equation is:

$$A = P \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \qquad (2.22)$$

Both of these methods have some variables which are symbolized like below:

P = Present worth

F = Future sum

A = Equal payment series

i = interest rate
f = inflation rate
n = number of years

b) Contemporary LCC methods:

Value-oriented LCC approach,

Value-oriented LCC approach focuses on the components of product. This method evaluates the whole life cycle costs of product bases on the function of a product components and the value of these components. It is a redesign approach has been developed considering the perspective of a designer who wants to improve product performance over the whole life-cycle while in order to optimize costs. Product components can be identified which incur high costs compared to their functional value. In order to identify the most optimized potential (Janz et al., 2005).

Base case approach,

This approach enables comparative LCC estimation to compare two product one is new product and a product which is a representative sample implemented in advanced. This method can be applied to the whole product, or to different parts or components of product (Kaya, 2009).

The approximate LCC method,

The approximate LCC method like base case approach, it enables the comparative LCC estimation to be made between the different product concepts(Park et al., 2002).

(Levander et al., 2014) have summarized the economic evaluation methods for LCC and compared them regarding to their advantages and disadvantages, and where can be applicable.

Table 2.1 shows this comparison between different LCC calculation methods.

LCC uses net present value (NPV) concepts. NPV is an important economic measure for projects or devices taking into account discount factors, cash flow, and time. Net present value calculations start with a discount rate, followed by finding the present value of the cash proceeds expected from the investment, then followed by finding the present value of the outlays, the net of this calculation is the net present value. Cash availability and strategies aside, when competing projects are judged for acceptance, projects with high NPVs usually win (Barringer et al., 1997; Levander et al., 2014).

Table 2.1

The advantages and disadvantages of economic evaluation methods for LCC, source (Levander et al., 2014)

Method	What does it calculate	Advantage	Disadvantage	Usable for
Simple payback.	Calculates the time required to return the initial investment. The investment with the shortest payback time is the most profitable one .	Quick and easy calculation. Result easy to interpret.	Does not take inflation, interest or cash flow in to account.	Rough estimation to see if the investment is profitable.
Discount Payback method (DPP).	Basically the same as the simple payback method, it just takes the time value into account.	Takes the time value of money into account.	Ignores all cash flow outside the payback period.	Should only be used as a screening device, not as a decision advice.
Net present value (NPV).	NPV is the result of the application of discount factors, based on a required rate of return to each years projected cash flow, both in and out, so that the cash flows are discounted to present value. In general, if the NPV is positive it is worthwhile investing. But as the focusing LCC is on cost rather than on income, the usual practice is to treat cost as positive and income as negative. Consequently, the best choice between two competing alternatives is the one with minimum NPV.	Takes the time value of money into account. Generates the return equal to the market rate of interest. It uses all available data.	Not usable when the comparing alternatives have different life lengths. Not easy to interpret .	Most LCC models utilize the NPV method. Not usable if the alternatives have different life lengths.
Equivalent annual cost (ECA).	This method expresses the onetime NPV of an alternative as a uniform equivalent annual cost. For that it takes the factor present worth of annuity into account.	Different alternatives with different life lengths can be compared.	Just gives an average number. It does not indicate the actual cost during each year of the LCC.	Comparing different alternatives with different life lengths.
Internal rate of return (IRR).	The IRR is a discounted cash flow criterion which determines an average rate of return by reference to the condition that the values be reduced to zero at the initial point of time. It is possible to calculate the test discount rate that will generate an NPV of zero. The alternative with the highest IRR is the best alternative.	Result gets presented in percent which gives an obvious interpretation.	Calculations need a trial and error procedure. IRR can only be calculated if the investments will generate an income.	Can only be used if the investments will generate an income, which is not always the case in the construction industry.
Net Saving (NS).	The NS is calculated as the difference between the present worth of the income generated by an investment and the amounted invested. The alternative with the highest net saving is the best	Easily understood investment appraisal technique.	NS can only be used if the investment generates an income.	Can be used to compare investment options. But only if the investment generates an income.

2.11 LCC and Software

Since the early 1990s, there has been a significant development of LCC, both in terms of methodology and applications. Information Technology (IT) tools were used to assist decision makers in the process of calculations, however the objectives of applying IT tools in the LCC domain are to make the work faster, easier in estimating and summarizing life cycle costs accurately, with clarified breakdown costs and comparisons with risk assessment for any type of investment (Rahman and Vanier, 2004).

Many different types of softwares were used in LCC and has been seen in different literatures, as (Rahman and Vanier, 2004) mentioned these softwares fall into two main categories: standalone and integrated softwares:

2.11.1 Standalone Softwares:

Many specialized areas use standalone products such as buildings, bridges, pavement management, and machinery parts because these applications support the evaluation process of proposed alternatives leading to final decision-making

A limited number of examples of standalone IT tools are listed below:

- Microsoft Excel has incorporated widely in financial functions since it can assist in the calculation of LCC. Where The Microsoft Excel spreadsheet has functions to calculate the present value (PV), the future value (FV), as well as, annualized payments (PMT).
  D-LCC cost breakdown of elements is represented in the form of a tree structure that is created interactively by the application
- LccWare, a project wizard simplifies the creation of new projects with detailed cost libraries. Sensitivity analysis and report generation are common features for such types of software
- The Relex software
- BLCC This software calculates the present value of the LCC net savings, savings-to-investment ratio, internal rate of return, and payback period for the all propose alternatives, it also provide a summary of energy savings and emission reductions(National Institute of Standards and Technology-NIST, 1996)The advantage of this tool is for planning the maintenance and renewal of municipal assets are readily evident, even though it can't be directly applied
- WLCC; this program needs Microsoft Excel to generate the output from a Monte Carlo simulation. It calculates the LCC as whole life cycle cost (WLCC) for a 50 years as a maximum analysis.

Generally, these tools perform visual interface to calculate the net present value (NPV) of the system (device), net savings, savings-to-investment ratio, internal rate of return, and payback period for each alternative. In addition, it performs a summary of energy savings and emission reductions. Sensitivity analysis and report generation are common features for such types of software.

The data inputs are the general project information and project costs such as initial capital costs, residual value, regular maintenance cost, operational costs and other non regular costs. Table 2.2 shows some examples of standalone IT tools, their features and details as mentioned in

Table 2.2
examples of standalone IT tools, along with details of their software features source (Rahman and Vanier, 2004)

Software	Produced by	Applications	Features
Microsoft Excel	Microsoft Corporation (Website [3])	Database and LCC Calculations.	Spreadsheet for data analysis, graphical interface, mathematical and statistical functions for cost calculation
D-LCC	SoHaR Incorporated (Website [4])	Software and hardware reliability, LCC for transportation and aerospace.	Networkable, multi-user options, cost breakdowns, visual interface with costing model, library facility, and report generation capability.
LccWare	Isograph Inc (Website [5])	System reliability, maintainability, LCC and integrated logistic support.	Visual interface with cost model, online cost calculator, project wizard, cost library, security model, report generator, and graphing facilities.
Building Life Cycle Cost (BLCC)	National Institute of Standards and Technology (NIST) (Website [6])	Building facilities, nuclear and energy sector.	Two modules for water and energy related LCC for buildings, comparative analysis report, net savings, uses current cost values, user friendly.
Relax 7.6	Relex Software Corporation (Web site[7])	System reliability, maintainability, LCC of integrated facilities.	Cost breakdown modeling with visual interface, library functions, online help and integrated cost calculator.
WLCC V1.1 (Liverpool)	University of Liverpool (Web site[8])	LCC for buildings and facilities.	Project cost input options and Monte Carlo simulation for LCC calculation

2.11.2 Integrated Systems

Few integrated systems were seen in literatures which aim to calculate LCC for systems (devices), where the most existing systems can deal with specific applications. Most of these softwares are applicable for specific domain and are not applicable with others.

Examples of an integrated system

i. FHWA's RealCost LCC software (Salem et al., 2003). It calculates the life cycle costs for construction domain.
ii. Pipeline Asset & Risk Management System (Commonwealth Scientific and Industrial Research Organization (CSRIO) and Flagships, 2003), a research product of the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, is currently being developed to analyze the whole life cost (WLC) implications of a range of scenarios related to bury infrastructure (Rahman and Vanier, 2004).
iii. Packaging Industry Research Association (PIRA) Environmental Management System Software Version 4, known as PEMS.4.Manufactureres are developing software based on historical data. Because of the complexity of costs estimating, these softwares are good helper in life-cycle-cost analysis (Seyffer et al., 2010).

2.12 Conclusions of the Literature Review

From all above literature review, the following distinct points can be concluded:

- A systematic review of literature has present information on theory behind lifecycle costing, the importance of the life-cycle costing, the history of the life-cycle costing, the models and the methods for using life-cycle costing to control system costs
- Most of the reviewed articles included in this systematic review stated that the life cycle costing is a great tool to reach the best decisions made especially for those in the earlier stages of the device life in the design phase cause it has a great influence over the cost optimization along the device life.
- The articles stressed the importance of realizing that a lower initial acquisition cost does not necessarily result in a lower total life-time cost Such saving by choosing the lowest acquisition at the beginning of the device life may be followed with huge expenditure along its life span
- A general models and specific models have developed to simulate the studied system (device) in order to forecast the future costs using

life cycle costing methods which discussed above to find the suitable alternative with the lowest life cycle cost value

- Although there is a substantial amount of literature available on the process of using life-cycle costing, and its potential benefits, little research has been done to explore the effect of the life cycle cost in medical devices management, and/ or taking decisions related to them
- No related research of applying life cycle cost in medical devices in Jordan has found. Even though it will be very helpful and applicable in different phases of maintenance, and purchasing procedures and can be a vital improvement tool for the management of the medical devices
- Varity number of literatures discussed the LCC procedure bases on Harvey's life cycle costing procedure in identifying cost elements, cost structure and find the relationship between all of these elements, and the Kaufman's life cycle costing formulation which is more comprehensive than Harvey's procedure and contains all the possible cost elements of a system
- All the cost elements and needed parameters calculations were discussed, to be clearly identified as a fundamental to be implemented Kaufman's life cycle costing structure reaching the most possible precise LCC.

Chapter Three

Methodlody

The methodology used in this study focused on different costs categories for two alternatives of medical devices from different companies that have the same function, thereafter the final LCC values will be the guide to make decision about these studied two models.

The operating cost was obtained from technical operators who have full responsibility to operate the medical device, and the historical reports.

The data collected from the historical maintenance recodes focused on the initial cost (purchasing and installation costs), maintenance costs related to the corrective and preventive maintenance, the installation date of the device, and number of failures. This information was invested in calculating the critical cost parameters as well as the LCC values.

The target medical devices used in this study include devices from three main groups:

- Laboratory Devices: two different models of Electrolyte device Easylyte Plus (Model 1), Medica Corporations, USA and AVL-9180 (Model 2), AVL scientific corporation. (Roche), USA
- Radiology Devices: two models of X-rays devices UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2)
- Pediatric devices: two models from Infant incubator were selected including Air shields C450, Vickers PLC Company, UK (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2) (Table 1.1).

Moreover, the researcher own experience was involved to fill the gaps in the information between the operator and the historical records.

In this study, Net Present Value (NPV) concept was used in calculating LCC. After collecting the required data separately for each year including the running costs and the income of the device, the NPV was discounted back to the base year based on the interest rate of return and the inflation rate for each year. This will make the comparison between any two alternative devices more logical (Barringer et al., 1997; Levander et al., 2014). However, as the income of the device is greater than the costs and the LCC focuses on the costs, and since the device incomes of each competing alternatives are close, the income of each device were omitted from the final calculations of the LCC.

3.1 Area of Study

The nature of the data collected in this case study describes six major medical devices mostly used in three different hospital departments (Table 1.1) in Al Karak hospital, Al Karak district, Jordan. The study area was described in chapter 1, section 1.9.

3.2 Data Collection

On the ground, there was no way to set a minimum or maximum life of the devices, as there were wide variations in working load and working environment from device to device from the same model. Some devices from the same model did not subjected to high number of maintenance actions, which run happily for years due to extremely low working load on the device. However, other devices subjected to continuous maintenance, due to high working load. To represent the real life span of the device and to take reliable estimate of LCC, the devices were selected from a particular model according to its historical records or more precisely, only those devices that subjected to higher number of maintenance actions were selected for LCC estimation and for comparison between two alternative models.

The usual procedure of running policy of medical devices in Ministry of Health (MOH) basically consists on the use of equipment until the end of its physical life, which cannot be maintained anymore. There is no specific methodology to determine the LCC for medical devices. The decision is mostly based on the sense and work experience of technical engineers, who work supervising the maintenance of the devices, and Biomedical Directorate personnel, who are responsible for the management of the medical device at governmental hospitals in Jordan.

3.3 LCC Estimation Procedure

To estimate the LCC for the selected medical devices, the Kaufman approach (Woodward, 1997) of eight steps for LCC analysis will be used. These steps are listed below:

Step1**:** Determine two different alternative models from two different manufacturer sources that have the same function.

Step 2: Collect the required data regarding to the historical maintenance reports, historical operator reports and other information from the site engineers if required.

Step 3**:** Estimate an appropriate LCC categories using Kaufmann

estimation approach for LCC(Woodward, 1997).

- Define operating profile.
  The operating time profile per day was estimated by the operator for each device.

- Establish the utilization time(UT) of the device as follows:

$$UT = N \times T \quad (3.1)$$

UT = Utilizing time

N = Average number of served patients per day according to the operators

T = Time required for each service

- Identify the cost elements including; initial cost, total operating cost, total maintenance cost (corrective and preventive maintenance), the income from the device, and the salvage value.
  - The total operating costs is the sum of the required costs to put the device in service including operator man-hour cost, materials (reagents) costs, and the electrical power cost. All these data were collected from the operator
  - The total maintenance cost consists of the cost related to the corrective maintenance and to the preventive maintenance taking into consideration the man-hour cost and the spare parts cost. It was collected from the historical maintenance records.
  - The device income (DI) was calculated using the following equation:

$$DI = N \times T \times C \quad (3.2)$$

Where

N= The number of operating days

T = The number of performed services

C = The cost of the service

These data were collected from the operator, the value of this category expected to be very close for the two alternative models, as they have the same load and the same number of served patients or samples per day. This will lead to unbiased comparison between the two alternatives.

-The last cost category is the salvage value (S), which was calculated using the following specific equation (Panneerselvam, 2012).

Taking into consideration linear depreciation of 10%:

$$S = C(1 - D)^n \qquad (3.3)$$

Where,

S: salvage value

C: original price

D: depreciation rate

n: age in years.

- Identify the most critical cost parameters which control the degree of the costs incurred during the life of the device. This stage is illustrated in figure 3.1. The most significant cost parameters are:

❖ **MTBF (Mean Time between Failures)**;

Time period between failures (Kaufman's 'MTBF'); is calculated by dividing the operating time by the number of failures. It is used as an indicator for maintenance of equipment. The MTBF is typically a part of a model that assumes the failed system is immediately repaired or with a finite period of time.

The definition of MTBF depends on the definition of what is considered a system failure (Dhillon, 2010).

$$\text{MTBF} = \frac{\sum(\text{Start of Downtime} - \text{Start of Uptime})}{\sum \text{Number of Failures}} \qquad (3.4)$$

The inverse of MTBF is the failure rate, λ. So, the device constant failure rate λ could be estimated as follows:

$$\lambda = \frac{1}{MTBF} \qquad (3.5)$$

❖ Mean Time to Repair (Kaufman's 'MTTR');

MTTR is used as a measurement for maintenance to establish a baseline for repair time and then strive to reduce time in order to return equipment faster to working orders. It can be calculated as total maintenance repair time divided by the total number of maintenance repair actions during a given period of time. It is sometimes called mean corrective maintenance time (Website [9]).

$$\text{MTTR} = \frac{\sum \text{Repair Time}}{\sum \text{Number of Repair actions}} \qquad (3.6)$$

The device constant repair rate μ;

$$\mu = \frac{1}{MTTR} \qquad (3.7)$$

Figure 3.1 shows these three parameters MTTF, MTTR and MTBF

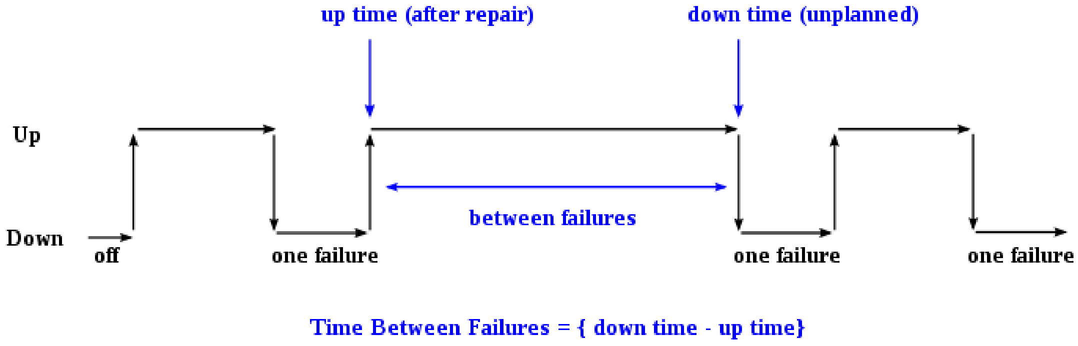


Figure 3.1

Critical cost parameters MTBF, MTTR source (website [3]).

The failure rate and the repair rate are used in the availability of the device and the unavailability.

- **Device Availability (AV)**

The device availability is the percentage of time when it is operational (Dihllon, 2008).

$$\mathrm{AV} = \frac{\mathrm{MTBF}}{\mathrm{MTBF} + \mathrm{MTTR}} \qquad (3.8)$$

$$AV = \frac{\mu}{\lambda + \mu} \qquad (3.9)$$

- **Device Unavailability (UAV)**

The unavailability (UAV) of the device when it doesn't operate because of failure:

$$UAN = \frac{MTTR}{MTBF + MTTR} \qquad (3.10)$$

$$UAV = \frac{\lambda}{\lambda + \mu} \qquad (3.11)$$

- **Time period for scheduled maintenance**;

The preventive maintenance scheduled to be performed once yearly. All costs should be calculated at current rates.

Kaufman approach concedes the inflation rate in the LCC calculation, so it was important to concede it in NPV calculations. The Jordanian central bank reports were the source of such information over the previous ten years.

Discounting back all costs to the base period. It is known that money which has a time value and the cash flows developing in different time periods are discounted back to the main period to warrant equitability using a discount factor mentioned in section 2.10.2 equation (2.20).

LCC could be estimated by summing the discounted costs to establish the net present value. Integrating all of these cash flow categories at a specific year will produce the yearly LCC for each device.

Our LCC model which derived from the general model mentioned in section 2.10.1equation 2.18 is:

$$LCC = C + O + M - S \qquad (3.12)$$

Where,

C = the capital cost

O = the operation cost (man – hour cost, reagents,

disposables cost and power cost)

M = the maintenance cost (corrective and preventive

maintenance)

S = the salvage value

The device income in our model was omitted because if the income values are included in our calculations, negative LCC values will be obtained. Our model for LCC estimation focused mainly on the costs that might occur during the device life.

The comprehensive equation used to calculate the total LCC value at the determined base year includes the cost categories and the discounting factor is:

$$LCC = C + \left(\frac{1+f}{1+i}\right)^{n} \sum_{1}^{n} O + M - \left(\frac{1+f}{1+i}\right)^{n} \times S \quad (3.13)$$

Where ,

C = the capital cost

O = the operation cost (man – hour cost, reagents,

disposables cost and power cost)

M = the maintenance cost (corrective and preventive

maintenance)

S = the salvage value

f = inflation rate

i = interest rate.

Step 4: Find the deterministic model for each model to forecast the LCC values for five years more in future.

Step 5: Taking decisions which model is better to be purchased and maintained over its physical life.

3.4 Statistical Analysis

The Pearson correlation coefficient was used to measure the strength of the relationship between LCC and the device age. Pearson's r could be ranged from -1 to 1. An r less than zero indicates negative linear relationship between variables, and when r more than zero indicates a perfect positive linear relationship between variables.

A simple linear regression was used to estimate the regression coefficient (b), the coefficient of determination (R^2) and the standard error. Linear regression was used to investigate the relationship between LCC (the response variable) and device age (the explanatory variable). Also, the regression equation was used to predict the future life cost based on the available historical data.

A paired t-test was used to look at the difference between paired LCC values came from the two alternative models. For paired t-test, the null hypothesis was tested that the true mean values of LCC differences between two models over yeas are zero, against the alternative hypothesis that the mean differences in LCC values between the two alternative models are significantly different.

Chapter Four

Results of LCC Analyses

This part describes the estimation of LCC for the three groups of medical devices as case studies (see Table 1.1). The purpose of these case studies is to compare between two alternative models in terms of LCC. This will help the decision makers to select the best alternative model, which gives the lowest cost during the device life span.

The data was collected for devices to estimate LCC values for the period extended from the installation year up to 2013.

Based on historical data, it was possible to collect the required data for LCC estimation for each particular model.

For each case study, the two alternative models were selected based on the historical maintenance records and its performance over its life span, having the same function and working under the same operating and maintenance conditions. One device from each model was selected which displayed the highest maintenance actions according to the review of historical maintenance records available in the hospital to get reliable estimation of LCC.

4.1 Case Study 1 (Electrolyte devices):

The two electrolytes models are extensively used in laboratory department for chemical analysis of blood, which measure the Na^+, K^+, Cl^-, Li^+, ions concentration in the blood serum. The two models were compared; namely, Easylyte Plus (Model 1), Medica Corporations, USA (Medica Corporation, 2003) and AVL-9180 (Model 2), AVL scientific corporation. (Roche), USA (AVL Scientific Corporation, 1996). Their initial costs are 4000 and 3593 JD, respectively. The two models with minor differences in specifications as can be seen in Table 4.1.1. The minor differences include the time required for analysis and both weight and dimensions. The analysis time for Easylyte Plus is 55 sec per sample, whilst it is 50 sec per sample for AVL-9180. The weight and dimensions were 5.8 kg and (24×42×20) cm^3 for Easylyte Plus and 4.8 kg and (31.5×33.5×30.5) cm^3 for Avl-9180.

The following steps describe the LCC analysis procedure for the two models as previously mentioned in the methodology section 3.3:

Step 1: Two alternative models were determined as they are only two available models in the hospital. One device from each model which displayed the highest maintenance actions were selected to estimate its LCC over its lifespan.

Step 2: After identifying possible device alternatives, the historical data regarding the corrective and preventive maintenance, the used spare costs and man hour costs were collected. Another subset of the data was collected from operators to estimate the total operating costs.

Step 3: Estimate the LCC using Kaufmann estimation approach (Woodward,1997) independently for each year as follows:

1- Define operating profile.
The two models are operating along the day and night

hours to be utilized any moment, so it was assumed that the

operating time to be 24 hr/day.

2- Establish the utilization factors of the device.
Estimation the daily utilization factor for each model was

estimated by averaging the number of tests per day.

Thereafter, the total number of tests was calculated over the whole year.

For Easylyte Plus, the average utilization time per

year ranged from 733.7 hours/ year, ranging from 632.5 to

809.6 hours / year, for the period extended from 2008 to 2013. The average corresponding values for AVL- 9180 were 695.72 hours/ year ranging from 604.07 to 729.05 hours/ year for the period extended from 2008 to 2013.

The utilization time for the two models is slightly

differed according to the time needed to perform each test

(55 sec/ test and 50 sec/ test for Easylyte Plus and Avl-9180, respectively). However, when these values were calculated as annual averages, an obvious difference in the operating cost was found.

3- Identify the cost elements including initial cost, operating cost (Tables 4.1.4, and 4.1.5), maintenance cost (Tables 4.1.6, and 4.1.7), the device income and the salvage values (Table 4.1.8, and Table 4.1.9) for both models which are Easylyte Plus and AVL- 9180, respectively.
4- Identify the most critical cost parameters which control the degree of the costs incurred during the life of the device. The most significant of these are: Mean time period between failures (Kaufman's 'MTBF'), Mean time to repairs (Kaufman's 'MTTR'), time period for scheduled maintenance and energy use rate. Tables 4.1.2 and 4.1.3 show the details of these parameters for Electrolyte Plus and AVL- 9810, respectively.

Easylyte Plus's displayed lower MTBF, failure rate,and unavailability values as compared to AVL–9810. The average values for MTBF were 4.1.16 day / year (range =21.54 to 91.33 day /year) (Table 4.1.2) and 34.36 day / year (range =18.67 to 53 day/ year) (Table 4.1.3) for Easylyte Plus and AVL – 9180, respectively. This means that the Easylyte Plus worked effectively for 7 days per year more in average with less fails over the last 6 years (from 2008 to 2013) as compared to AVL-9180.

The availability factor as a critical parameter to compare between the two models over the last 6 years. From 2008 to 2013, the availability was 87.01% (range = 75.87 % to 96.83 %) for Easylyte Plus (Table 4.1.2) and 84.31 % (range= 42.75 % to 95.21%) for AVL -9180 (Table 4.1.3 and Figure 4.1.1). Even though the Easylyte Plus life span is longer than AVL -9180, historical data proved that the Easylyte Plus was more effective in the critical cost parameters. As the previous critical parameters, the average failure rate was better for Easylyte Plus (average = 0.030; range = 0.011 to 0 .046) with 10 years' service (Table 4.1.2), than the corresponding value for AVL - 9810 with its shorter life span (6 years service) (average = 0.034; range = 0.019 to 0 .054) (Table 4.1.3). Figure 4.1.2 shows the failure rate for the both models.

Even though the devices were brand new, the historical data showed that both models started to fail from the first year of installation which might be due to low experienced operators at the beginning of the device life span. Most failures in the early years were concerned with calibration

and cleaning related issues.

The difference in MTTR and repair rate was marginal. The MTTR parameter was slightly less for Easylyte Plus (average =6.04; range = 1 to 16 day / year) (Table 4.1.2) than for AVL - 9810 (average =6.58 day / year; range = 2 to 25 day / year) (Table 4.1.3). Moreover; the repair rate ranged from 0.06 to 0.91(average = 0.38 days required for repair/number of repairs) (Table 4.1.2) and from 0.04 to 0.53 (average = 0.33 days required for repair/number of repairs) for Easylyte Plus and AVL - 9810, respectively (Table 4.1.3).

Even though Easylyte Plus has been installed 4 years

before the AVL - 9810, its repair rate is slightly higher indicating that it needs less time to be repaired and return to service after break down, using the same maintenance techniques and procedures.

5- To estimate the values for the initial cost, the total operating costs, the total maintenance costs, the device income and the salvage value of the device were estimated at the current rates.
The initial cost for Easylyte Plus (4000 JD) is 10.2% higher than that of AVL - 9810 (3593 JD).

Total operating cost was calculated by summing the consumable costs, the man- hour cost, and the energy cost. For Easylyte Plus, the average operating cost over the studied years was 7317.97 JD / year, ranging from 6272.27 to 9371.36 JD / year in the period extended from 2008 to 2013 (Table 4.1.4). Lower calculated operation cost was found for AVL - 9810 with an average of 5940.55JD / year ranging from 5030.37 to 7725.51 JD / year for the period extended from 2008 to 2013(Table 4.1.5).

For both models the operation costs increase after 2012 due to increasing costs of man- hour (salaries of operators) and due to the increase in the number of tests and consequently the costs of consumables (Figure: 4.1.3).

The maintenance cost was calculated by summing the cost of the all corrective maintenance, including the man-hour cost and the cost of the replaced spare parts during the maintenance actions.

For Easylyte Plus, the maintenance cost during the first six years was

relatively low ranged from 23 JD /year to 65 JD/ year. During the last four years major maintenance action and spare parts replacement had occurred, which increased the maintenance cost to reach in average 545.43 JD/year. The maximum maintenance cost was 887.6 JD / year, which occurred in 2013. The minimum maintenance cost during the period extended from 2010 to 2013 was 108.9 JD / year. (Table 4.1.6).

Generally, the cost decreased after the maintenance actions and there was a fluctuated relation between the maintenance cost over years (Figure: 4.1.4). For Easylyte Plus device, the total maintenance cost comprised 61.29 % from the device initial cost: 5.23 % is spent during the first five years and 56.07% is spent during the last five years of the device life span. In this model, three major failures were occurred causing obvious increase in maintenance cost. This indicates the obvious increase in the maintenance cost by increasing the life time of Easylyte Plus device.

For AVL – 9810, the total maintenance cost over its whole life consists 24.15% from the device initial costs, which indicates the privilege of AVL-9180 as alternative to Easylyte Plus in terms of maintenance cost. In the first year, the maintenance cost was extremely low (14 JD/ Year) then it started to increase to reach the maximum in the third and the fourth years to be 218.2 JD/ year and 233.6 JD / year respectively, in the fifth year it decreased to 137.6 JD / year, and at 2013 it slightly increased to 154.4 JD/Year (Table 4.1.7).

The income from the two models is incomparable because they have the same number of performed tests and test costs. The marginal differences came from the differences in the break down period for each model; the average income of AVL - 9810 is 224964.6 JD / year (Table 4.1.5), ranging from 145700 JD / year to 383092.5 JD / year.

During the same period extended from 2008 to

2013, the income of Easylyte Plus ranged from 145660 JD / year to 383139.8 JD/year (average = 224876.2 JD/Year) (Table 4.1.4). For AVL - 9810 and Easylyte Plus, the income substantially increased in 2012 (383087.3 JD/ Year and 383139.8 JD/ Year respectively) and in 2013 (383087.3 JD and 382777.5 JD for AVL - 9810 and Easylyte Plus respectively) due to high number of analyzed tests as a result of the

increase in the number of patients. Tables 4.1.4 and 4.1.5 show the income of Easylyte Plus and AVL - 9810 respectively. Figure 4.1.5 shows the income of both models.

6- Based on the inflation and interest rate (Tables 4.1.8, and 4.1.9), the net of the all costs were discounted back to the base period. In this case, the base year was 2008 where all costs were discounted back to this year maintaining the comparison between the two different models .Tables 4.1.8 and 4.1.9 show the inflation rate and the interest rate as reported from the Jordanian central bank.
7- Summing the discounted costs to establish the net present value and reach LCC.

The LCC values will be discussed from two different point views:

1. For each model separately to monitor the yearly costs history over its life span from the installation year to 2013 and
2. By discounting back the LCC values to the base year 2008 in order to compare the both models' LCC values.

Easylyte Plus yearly LCC values ranged from 6680.71 to 12518.32 JD /year, with equalized average of 8609.21 JD / year (Table 4.1.8). The summing of all LCC values over the device life span after discounting them to the installation year release the total LCC values at the year of installation, which is 76510.32 JD.

AVL - 9810 LCC yearly values ranged from

5399.67 to 9480.93 JD / year, with an average of 7118.98 JD / year (Table 4.1.9). The total LCC of the device from 2008 to 2013 is 38426.74. Figure 4.1.6 shows both models LCC values.

For comparison between the two models, the device income will be omitted since the both models assumed to perform the same number of tests, and after calculations it was clear that the both models have the same income values (Figure 4.1.5). Omitting the income from LCC calculations will not affect the final decision regarding the best alternative. Moreover, including the device income make the decision even harder. Table 4.1.10 shows the LCC values for each model from 2008 to 2013 taking in consideration a discount factor based on year 2008 as a base year. The base year is the first year of having both models

in service. This makes the comparison more logical since the money value for each model in the period from 2008 – 2013 will be discounted back to the same year.

On average, Easylyte Plus displayed 25.45% higher LCC than AVL–9810 when comparing LCC discounted values. Easylyte Plus values ranged from 7771.69 to 12518.31 JD / year (LCC average = 9597.99 JD / year) and from 5399.67 to 9626.33 JD / year (LCC average = 7154.59 JD / year), respectively (Table 4.1.10).

Also comparing the LCC values for the first four

years (from 2004 to 2008) of the Easylyte Plus to the first four year of AVL - 9810 shows the same trend where the former LCC values were 25.5% higher than the later (Table 4.1.11). This bright the fact that the LCC values for Easylyte Plus is higher than AVL - 9810 from the years extended from 2008 to 2013 where both models were in service and regarding to the device age.

This indicates the Easylyte Plus is less efficient alternative for decision makers from LCC point view, even though it displayed lower failure rate and longer period of availability in service as compared with AVL - 9810. However AVL - 9810 showed lower initial purchasing cost and less operating and maintenance costs compared to Easylyte Plus.

Step 4: For this electrolytes study case, a deterministic model can be found from the historical data. Proposing functions can predict the total expected LCC values for certain model for a further (x) years of its possible life. Some statistics were performed for LCC values over years for both models including:

Pearson Correlation Coefficient:

Pearson correlation coefficients (r) were 0.998 and 0.928

between years and LCC values for Easylyte Plus and AVL - 9810, respectively (Table 4.1.12), which was significant at $\alpha = 0.01$. This indicates that the LCC increases with increasing the device age.

Linear Regression:

Linear regression was used to investigate the relationship between LCC (the response variable) and device age (the explanatory variable). The slope directly tells us about the relation between the mean LCC and the device age. When the true sample slope does not equal 0, the variables LCC and device age are linearly related. When the slope is 0,

there is no linear relationship because the mean of LCC does not change when the device age is changed. The null and alternative hypotheses for a hypotheses test about the slope are written as follows:

$$H_0 : \beta_1 = 0$$

$$H_A : \beta_1 \neq 0.$$

The regression equation was estimated for the available working years ranging from 2004 to 2013 for Easylyte Plus and from 2008 to 2013 for AVL- 9810. Results showed that significant regression between LCC and the device age at α = 0.0001 and 0.008 for Easylyte Plus and AVL - 9810, respectively. The ANOVA table for linear regressing analysis for both models is shown in Table 4.1.13.

A straight line regression model was fitted to the data. The resulting table of regression coefficients is shown in Table 4.1.14. The α-value for testing that the true value of the slope is <0.008(Table 4.1.14), so we reject the null hypothesis that LCC is not related to device age. The two variables are statistically significantly related: as the device age increases, so does the LCC. Regression (R^2) for the straight line regression model is 0.811 and 0.861 for Easylyte Plus and AVL- 9810, respectively (Figures 4.1.7 and 4.1.8). This means that just over 81.1% and 86.1% of the total variability in LCC has been explained by the straight line regression model. Figures 4.1.7 and 4.1.8 show a scatter plot of LCC against the device age, together with a straight line regression for Easylyte Plus and AVL - 9810, respectively. It suggests that the LCC increases linearly with increasing the device age.

The two representative equations of LCC for both models are:

- LCC equation for Easylyte Plus:

$$LCC(Model\ 1) = 5398.78 + 583.72\ x$$

- LCC equation AVL – 9810 :

$$LCC(Model\ 2) = 4022.98 + 884.57\ x$$

Where, *x* represents device age in year(s).

These two equations can be used to predict and evaluate the LCC values over the device future physical life. Applying the device age (x) in these functions for the next five years will give an idea about the devices behavior over years. These values for the following five years are shown in Table 4.1.15.

For the Easylyte Plus, the LCC values would slightly decreased for small amount for the two next year's due to major maintenance actions carried out during the year 2013, then increased again for the last three years by increasing the device age as some of the device parts would be expired after that and new maintenance actions might be required. The expected average LCC value for the next five years would be 12987.14 JD /year, where LCC expected values would

reach the maximum by the year 2018 (LCC = 14154.58 JD/ year); and the minimum value by 2014(LCC = 11819.7 JD/ year). Figure 4.1.9 shows the previous LCC values from 2004 to 2013 and the future expected values from 2014 to 2018.

AVL - 9810 LCC expected values for the next
five years would range from 10214.97 JD / year to 13753.25 JD / year with an average would equal 11984.11 JD / year. LCC values would substantially increase for this model reaching the maximum value after four years and slightly decrease again in the fifth year. Figure 4.1.10 shows the previous LCC values from 2008 to 2013 and the future expected values from 2014 to 2018.

Paired t-test:

For paired t-test, the null hypothesis was tested that the true
difference mean values of LCC for Easylyte Plus is the same as that for the AVL-9810 Model, against the alternative hypothesis that the true mean LCC value of diffrences is different for the two Models, i.e. we tested:

H_0: μ for Easylyte Plus ─ μ AVL-9810= 0

against

HA: μ for Easylyte Plus ─ μ for AVL-9810 ≠ 0,

where, μ denotes the true mean LCC for Easylyte Plus and AVL- 9810, respectively.

A two-sample paired t-test for testing the null hypothesis stated above gives α <0.01. So we reject the null hypothesis in favor of the alternative. This suggests that the mean LCC values for the two devices are significantly different.The observed difference between the LCC mean of the two models is 2489.83 JD with standard error of the difference of 156.51. t-calculate was significant at $\alpha = 0.0001$, suggesting that the true mean LCC value of the differences for Electrolyte Plus (LCC=9644.43) is higher than that for the AVL-9810 (LCC = 7154.59).

Table 4.1.1
Electrolyte Devices alternative models specifications

Specification	Easylyte Plus(Model 1)	AVL-9810(Model 2)
Manufacturer	Medica Corporation's Easylyte	AVL scientific corporation. (Roche)
Model	Easylyte Plus	Avl-9180
Environmental conditions	(15-32)°C humidity < 85%	(15-32)°C humidity (5-85)%
Location	Main hospital laboratory	Main hospital laboratory
Accessories	Operating and service manuals	Operating and service manuals
Installation Date	2004	2009
Dimensions	$(24{\times}42{\times}20)cm^3$	$(31.5{\times}33.5{\times}30.5)cm^3$
Weight	5.8 kg.	4.8 kg
Required power	220VAC, 50-60Hz	240 V AC, 50/60 Hz
Source	USA	USA
Analysis time	55 sec	50 sec
Complicity	Moderate	Moderate
operating time	24hr/ day	24hr/ day
Utilization time	2.3 hr / day	2.083 hr / day
Initial cost JD	4000	3593

Table 4.1.2

Critical cost parameters for Easylyte Plus, Medica, USA (Model 1) as calculated from historical data

Critical cost parameter	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mean time between failures yearly (MTBF)	64.167	80.6	25	37.5	91.33	33.125	44	23.4	33.6	21.54
Mean time to repair (MTTR)	3	5	2.5	9.6	15.667	1.25	4	7.4	1.1	6.85
Failure Rate (λ)	0.0155	0.0124	0.04	0.0267	0.0109	0.0301	0.0227	0.0427	0.0298	0.0464
Repair Rate (μ)	0.3333	0.2	0.4	0.1042	0.0638	0.8	0.25	0.1351	0.9091	0.1459
Device availability (%)	95.533	94.158	90.9	79.62	85.36	96.36	91.67	75.97	96.83	75.87
Device unavailability (%)	4.4665	5.8411	9.0909	20.382	14.642	3.6363	8.333	24.026	3.1700	24.128

Table 4.1.3

Critical cost parameters for AVL-9810, Roche, USA (Model 2) as calculated from historical data

Critical cost parameter	Year					
	2008	2009	2010	2011	2012	2013
Mean time between failures yearly (MTBF)	51.33	18.67	37.86	53	23.57	21.75
Mean time to repair (MTTR)	5	25	2.71	2.67	2.21	1.88
Failure Rate (λ)	0.019	0.053	0.026	0.019	0.042	0.046
Repair Rate (μ)	0.2	0.04	0.368	0.375	0.451	0.533
Device availability %	91.12	42.75	93.31	95.21	91.41	92.06
Device unavailability %	8.88	57.25	6.69	4.79	8.59	7.94

Table 4.1.4

The operating cost for Easylyte Plus, Medica, USA (Model 1) as collected from the operators and historical records

Operation category	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
No. of tests have been performed in a year	36500	36500	36500	36500	36500	36500	36500	36500	73000	73000
No. of reagent packs have been consumed in a year	36	36	36	36	36	36	36	36	48	48
The total cost of the reagents in a year	4140	4140	4140	4140	4140	4140	4140	4140	5520	5520
The man-hour cost for the operator	2065	2080	2095	2110	2125	2140	2155	2170	3820	3835
The cost of each test JD	4	4	4	4	4	4	4	4	5.25	5.25
The income of the device/ year	146000	146000	146000	146000	146000	146000	146000	146000	383250	383250
The no. of breakdown days / years	21	12	10	31	47	20	85	13	21	90
The cost of the break down period JD / year	84	48	40	124	188	80	340	52	110.25	472.5
The income of the device.	145960	145876	145960	145876	145812	145920	145660	145948	383139.75	382777.5
No. of utilizing hours in a year	791.2	811.9	816.5	695.722	731.4	793.5	644	809.6	791.2	632.5
The energy consumed in a year (K watt)	69.63	71.45	71.85	67.60	64.36	69.83	56.67	71.25	71.25	69.63
The average cost of the consumed power Fills/ KW*	82	82	82	82	113	113	114	144	204.5	235
Total electrical cost(JD)	5.71	5.86	5.89	5.54	7.27	7.89	6.46	10.26	14.57	16.36
The total operating cost	6210.71	6225.86	6240.89	6255.54	6272.27	6287.89	6301.46	6320.26	9354.57	9371.36
The % of the operating cost to the capital cost	155.27%	155.65%	156.02%	156.39%	156.81%	156.81%	157.54%	158.01%	233.86%	234.28%

Table 4.1.5

The operating cost for AVL-9810, Roche, USA (Model 2) as collected from the operators and historical records

Operation category	Year					
	2008	2009	2010	2011	2012	2013
No. of tests have been performed in a year	36500	36500	36500	36500	73000	73000
No. of reagent packs have been consumed in a year	36	36	36	36	48	48
The total cost of the reagents in a year	2880	2880	2880	2880	3840	3840
The man-hour cost for the operator	2125	2140	2155	2170	3820	3835
The cost of each test JD	4	4	4	4	5.25	5.25
The income of the device/ year	146000	146000	146000	146000	383250	383250
The no. of breakdown days / years	15	75	19	16	31	30
The cost of the break down period/ year	60	300	76	64	162.75	157.5
The device income.	145940	145700	145924	145936	383087.25	383092.5
No. of utilizing hours in a year	729.05	604.07	720.718	726.967	695.722	697.805
The energy consumed in a year (K watt)	224.55	186.05	221.98	223.91	214.28	214.92
The average cost of the consumed power Fills/ KW*	113	113	114	144	204.5	235
Total electrical cost(JD)	25.73	21.02	25.31	32.24	43.82	50.51
The total operating cost	5030.37	5041.02	5060.31	5082.24	7703.82	7725.51
The % of the operating cost to the capital cost	140 %	140.30%	140.84%	141.45%	214.41%	215.02%

Table 4.1.6
The maintenance cost for Easylyte Plus, Medica, USA (Model 1) as collected from the operators and historical records

Maintenance category	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Corrective maintenance										
• Spare parts cost	0	0	0	0	0	0	783.0	212	0.5	750.0
• Man-hour cost	60	50	33	27	19	61	55.8	126.4	104.4	133.6
Preventive Maintenance										
• Spare parts cost	0	0	0	0	0	0	0	0	0	0
• Man-hour cost	5	5	5	5	4	4	4	4	4	4
Total maintenance cost	65	55	38	32	23	65	842.8	342.4	108.9	887.6
%Maintenance cost related to the capital cost	1.75	1.5	0.825	0.675	0.475	1.53	21.07	8.56	2.72	22.19

Table 4.1.7

The maintenance cost for AVL-9810, Roche, USA (Model 2) as collected from the operators and historical records

Maintenance Category	Year					
	2008	2009	2010	2011	2012	2013
Corrective maintenance						
• Spare parts cost	0	100	179.8	150	0	0
• Man-hour cost	10	14	34.4	79.6	133.6	150.4
Preventive Maintenance						
• Spare parts cost	0	0	0	0	0	0
• Man-hour cost	0	0	4	4	4	4
Total maintenance cost	10	114	218.2	233.6	137.6	154.4
%Maintenance cost related to the capital cost	0.28	3.17	6.07	6.5	3.83	4.3

Table 4.1.8
The costs summery for Easylyte Plus, Medica, USA (Model 1) as calculated from the collected data from the operators and historical records

Cost category	Year									
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
The capital cost.	4000	3960	3920.4	3881.19	3842.38	3803.96	3765.92	3728.26	3690.98	3654.07
The total operating cost (JD).	6210.71	6225.86	6240.89	6255.54	6272.27	6287.89	6301.46	6320.26	9354.57	9371.36
The % of the operating cost to the capital cost.	155.27	155.65	156.02	156.39	156.81	156.81	157.54	158.01	233.86	234.28
The total maintenance cost (JD).	70	60	33	27	19	61	842.8	342.4	108.9	887.6
The % of the total maintenance cost.	1.75	1.5	0.825	0.675	0.475	1.53	21.07	8.56	2.72	22.19
The salvage value (JD).	3600	3240	2916	2624.4	2361.96	2125.76	1913.19	1721.87	1549.68	1394.71
The income of the device/ year.	145960	145876	145960	145876	145812	145920	145660	145948	383139.8	382777.5
The inflation rate (%).	2.6	3.5	6.25	4.7	13.9	-0.7	4.48	4.15	4.42	5.29
The interest rate (%).	2.49	3.52	5.13	5.56	5.66	4.23	3.4	3.46	4.19	4.97
LCC (JD).	6680.71	7005.86	7278.29	7539.34	7771.69	8027.09	8996.99	8669.05	11604.77	12518.32

Table 4.1.9
The costs summery for AVL-9810, Roche, USA (Model 2), as calculated from the collected historical data and the operators

Cost Category	Year					
	2008	2009	2010	2011	2012	2013
The capital cost.	3593	3557.07	3521.5	3486.28	3451.42	3416.91
The total operating cost (JD).	5030.37	5041.02	5060.31	5082.24	7703.82	7725.51
The % of the operating cost to the capital cost.	140.00	140.30	140.84	141.45	214.41	215.02
The total maintenance cost (JD).	10	114	218.2	233.6	137.6	154.4
The % of the total maintenance cost.	0.28	3.17	6.07	6.50	3.83	4.29
The salvage value (JD).	3233.7	2881.23	2567.17	2287.35	2038.03	1815.88
The income of the device/ year.	145940	145700	145924	145936	383087.25	383092.5
The inflation rate (%).	13.9	-0.7	4.48	4.15	4.42	5.29
The interest rate (%).	5.66	4.23	3.4	3.46	4.19	4.97
LCC (JD / year).	5399.67	5830.87	6232.83	6514.78	9254.81	9480.93

Table 4.1.10
Discounted LCC values for both electrolyte models, Easylyte Plus, Medica, USA (Model 1) and AVL-9810, Roche, USA (Model 2), over the years 2008- 2013

	Year					
Model	2008	2009	2010	2011	2012	2013
Model 1 (Easylyte Plus)	7771.69	7647.41	9185.92	8843.66	11707.58	12710.29
Model 2 (AVL-9810)	5399.67	5555.07	6363.71	6645.99	9336.80	9626.33

Table 4.1.11
Discounted LCC values for both electrolyte models, Easylyte Plus, Medica, USA (Model 1) and AVL-9810, Roche, USA (Model 2), regarding to each model age

	Device age (year)			
Model	1	2	3	4
Model 1 (Easylyte Plus)	6709.44	7001.79	7434.19	7477.92
Model 2 (AVL-9810)	5399.67	5555.07	6363.71	6645.99

Table 4.1.12
Results of correlations for both models as obtained from SPSS17.0 program

		Year	LCC (AVL-9810)	LCC(Easylyte plus)
Year	Pearson Correlation	1	0.939	0.931
	Sig.(1-tailed)		0.003	0.004
	N	6	6	6
LCC (AVL-9810)	Pearson Correlation	0.939	1	0.988
	Sig.(1-tailed)	0.003		0.0001
	N	6	6	6
LCC(Easylyte plus)	Pearson Correlation	0.931	0.988	1
	Sig.(1-tailed)	0.004	0.0001	
	N	6	6	6

Table 4.1.13
Results of ANOVA regression analyes as obtained from SPSS17.0 program

	Sum of squares	Degrees of freedom (df)	Mean square	F-value	Significance level (α)
			Easylyte Plus (Model 1)		
Regression	1.369×10^{7}	1	1.369×10^{7}	24.75	0.008
Residual	2212938.252	4	553234.56		
Total	1.591×10^{7}	5			
			AVL – 9810 (Model 2)		
Regression	2.811×10^{7}	1	2.811×10^{7}	34.359	0.000
Residual	6544881.113	8	818110.14		
Total	3.465×10^{7}	9			

Table 4.1.14
Results of regression coefficients for both models as obtained from SPSS17.0 program

	Unstandardized Coefficients		Standardized Coefficients		
	C	Std. Error	Beta	t-value	Sig.
			Easylyte Plus (Model 1)		
(Constant)(A)	5398.779	617.887		8.737	.000
device age(B)	583.715	99.582	.901	5.862	.000
			AVL - 9810 (Model 2)		
(Constant)(A)	4022.976	692.438		5.810	.004
device age(B)	884.573	177.802	.928	4.975	.008

Table 4.1.15
The expected LCC values for the next 5 years (2014 to 2018)

	Model	
Year	Easylyte Plus (Model 1)	AVL-9810 (Model 2)
2014	11819.7	10214.97
2015	12403.42	11099.54
2016	12987.14	11984.11
2017	13570.86	12868.68
2018	14154.58	13753.25

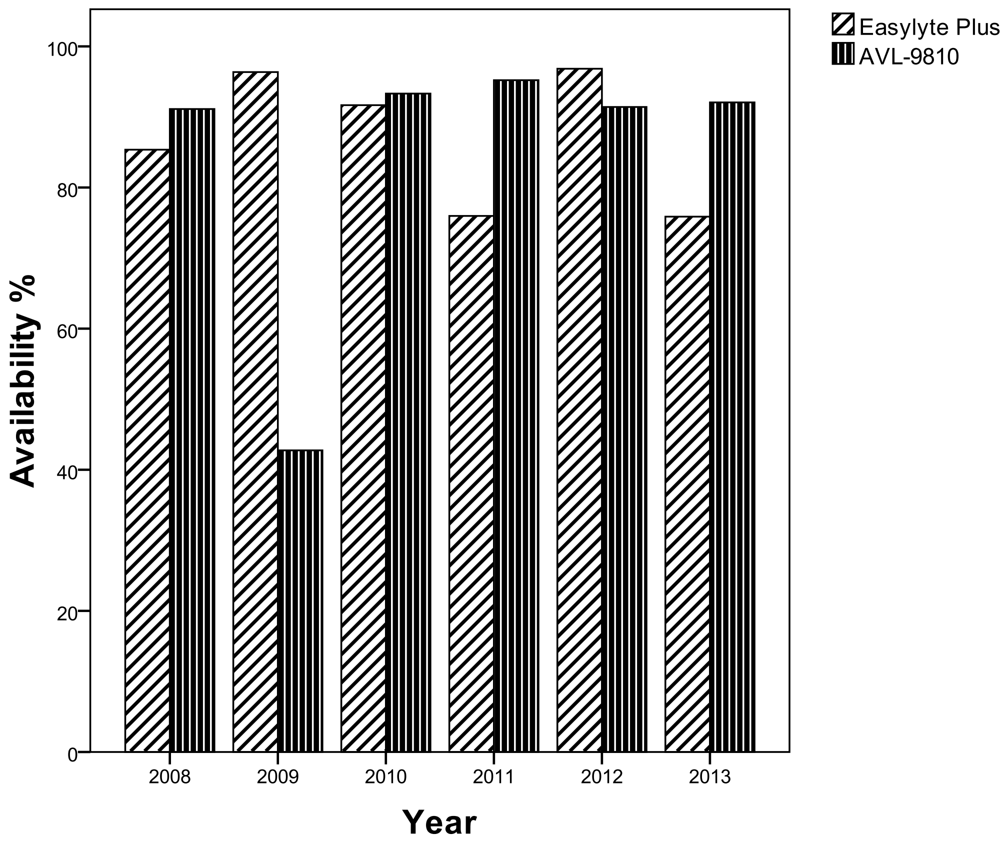


Figure 4.1.1
The availability % for the two electrolyte models: Easylyte Plus (Model 1) and AVL – 9810 (Model 2)

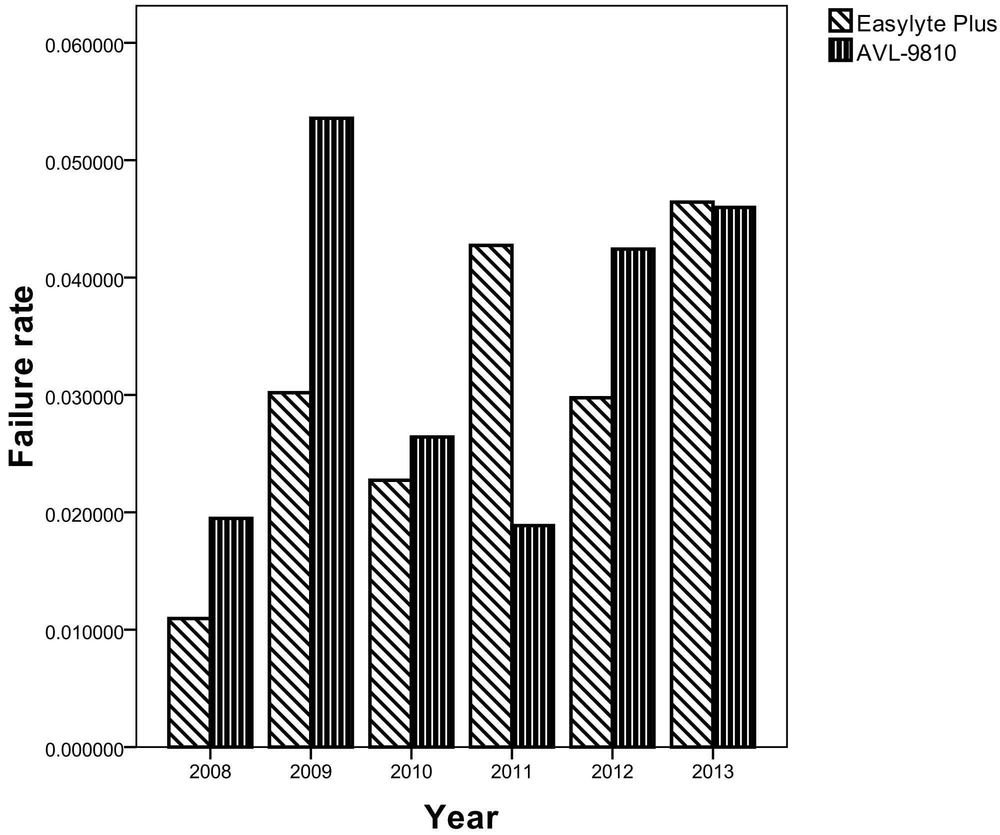


Figure 4.1.2
The failure rate for the two electrolyte models: Easylyte Plus (Model 1) and AVL – 9810 (Model 2)

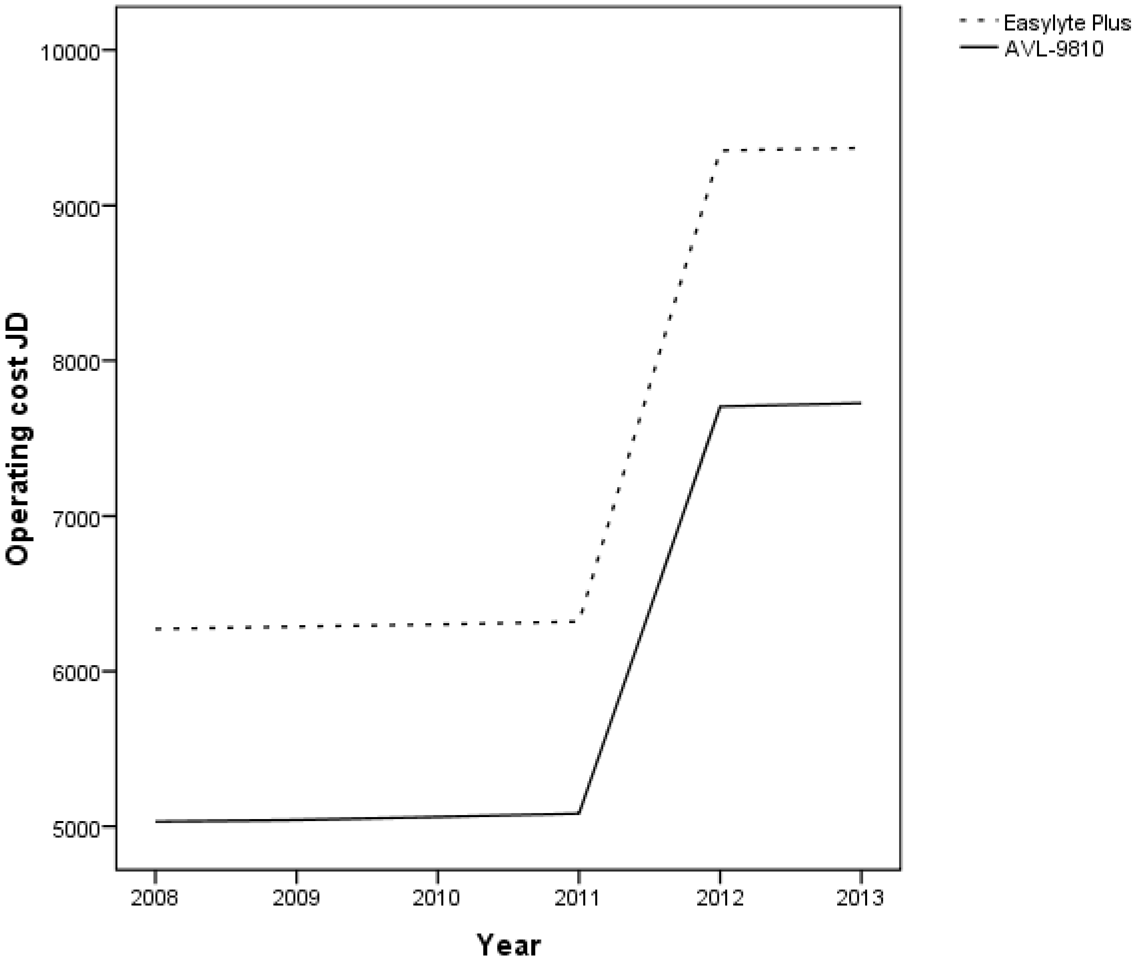


Figure 4.1.3
The operation cost for the two electrolyte models: Easylyte Plus (Model 1) and AVL - 9810(Model 2)

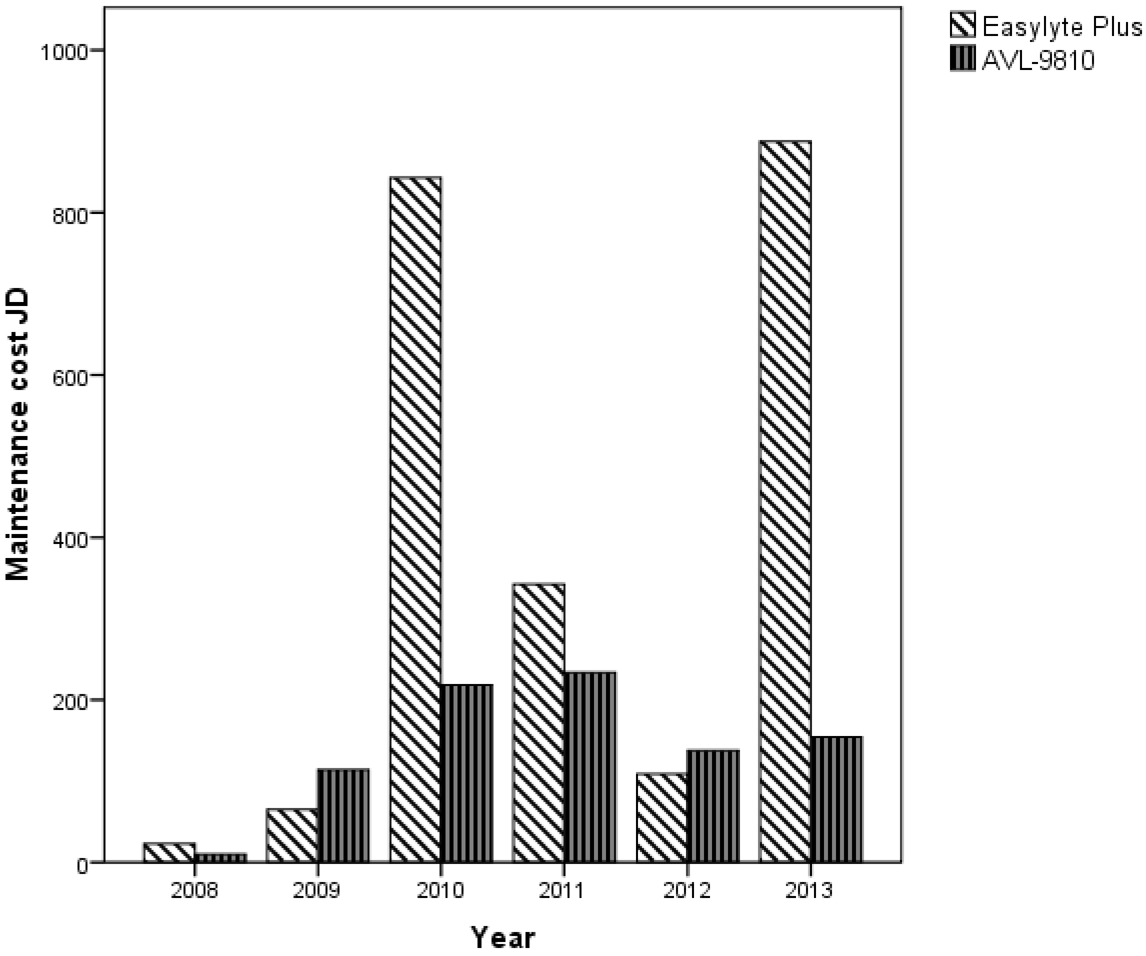


Figure 4.1.4
The maintenance cost for the two electrolyte models: Easylyte Plus (Model 1) and AVL – 9810 (Model 2)

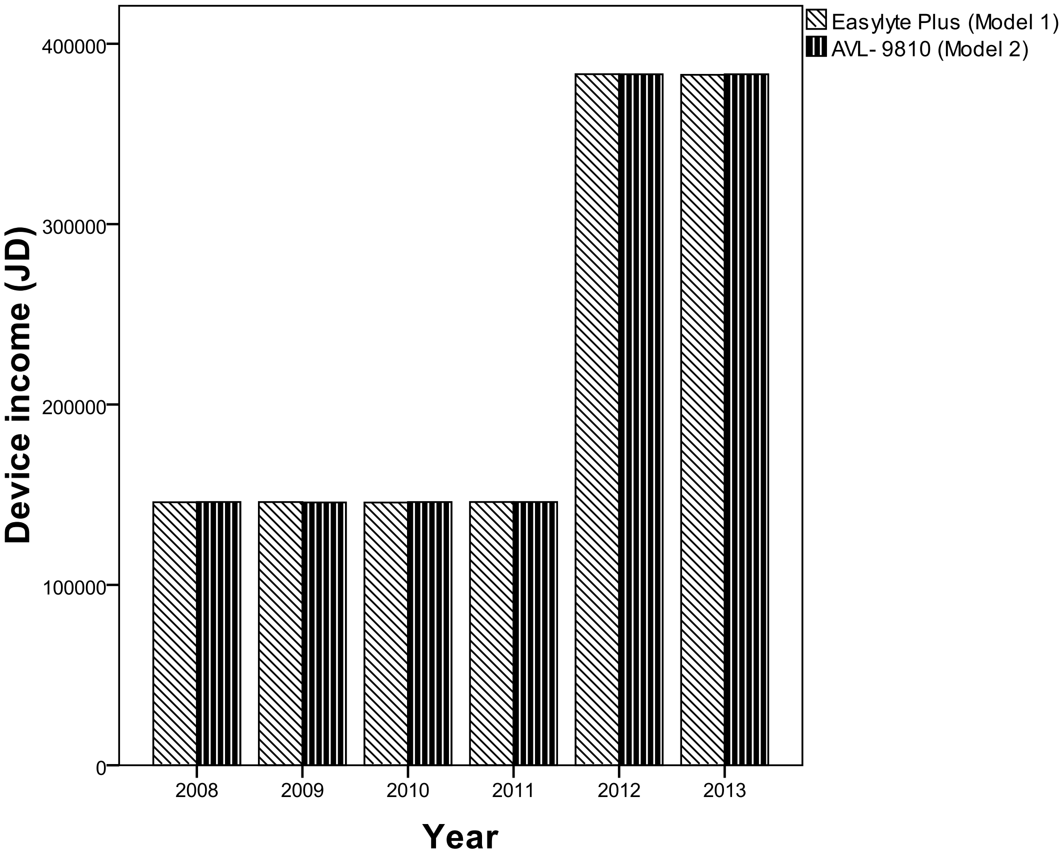


Figure 4.1.5
The device income for the two electrolyte models: Easylyte Plus (Model1) and AVL - 9810(Model 2)

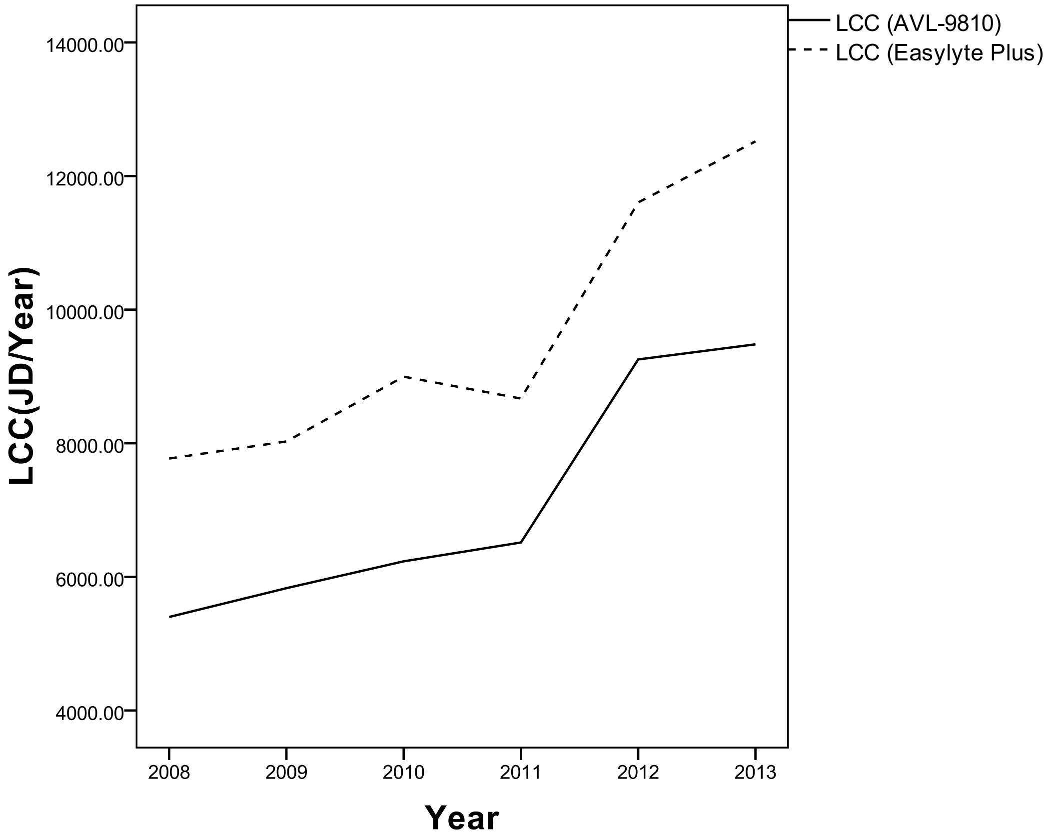


Figure 4.1.6
The LCC for the two electrolyte models: Easylyte Plus (Model 1) and AVL – 9810 (Model 2)

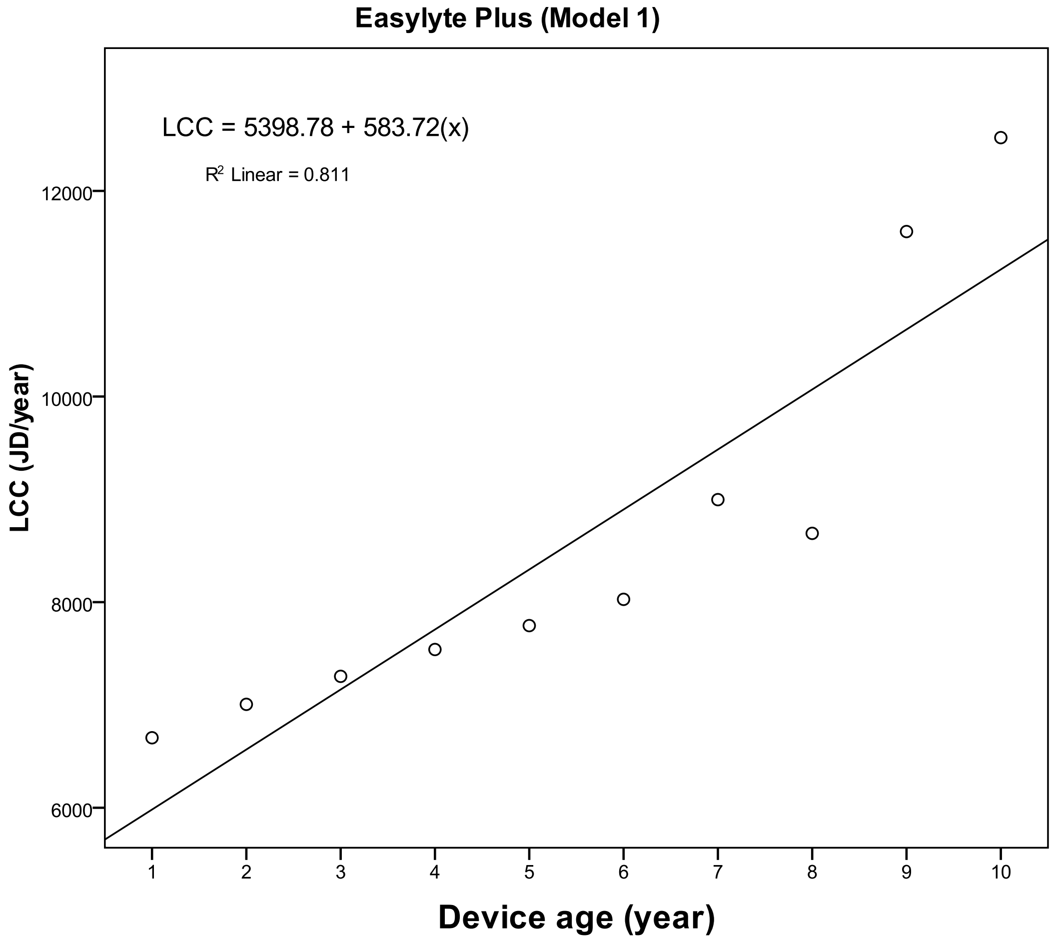


Figure 4.1.7
Scatter plot of LCC against the device age, together with a straight line regression for Easylyte Plus (Model 1)

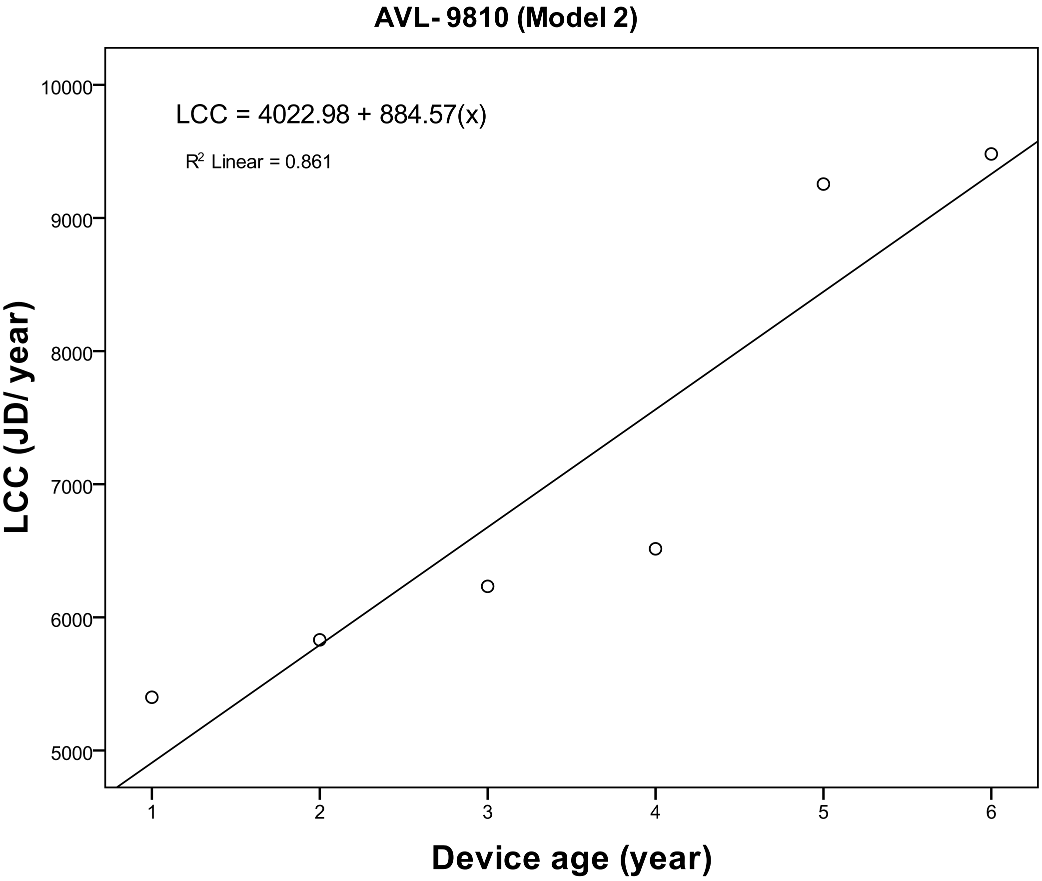


Figure 4.1.8

Scatter plot of LCC against the device age, together with a straight line regression for AVL – 9810 (Model 2)

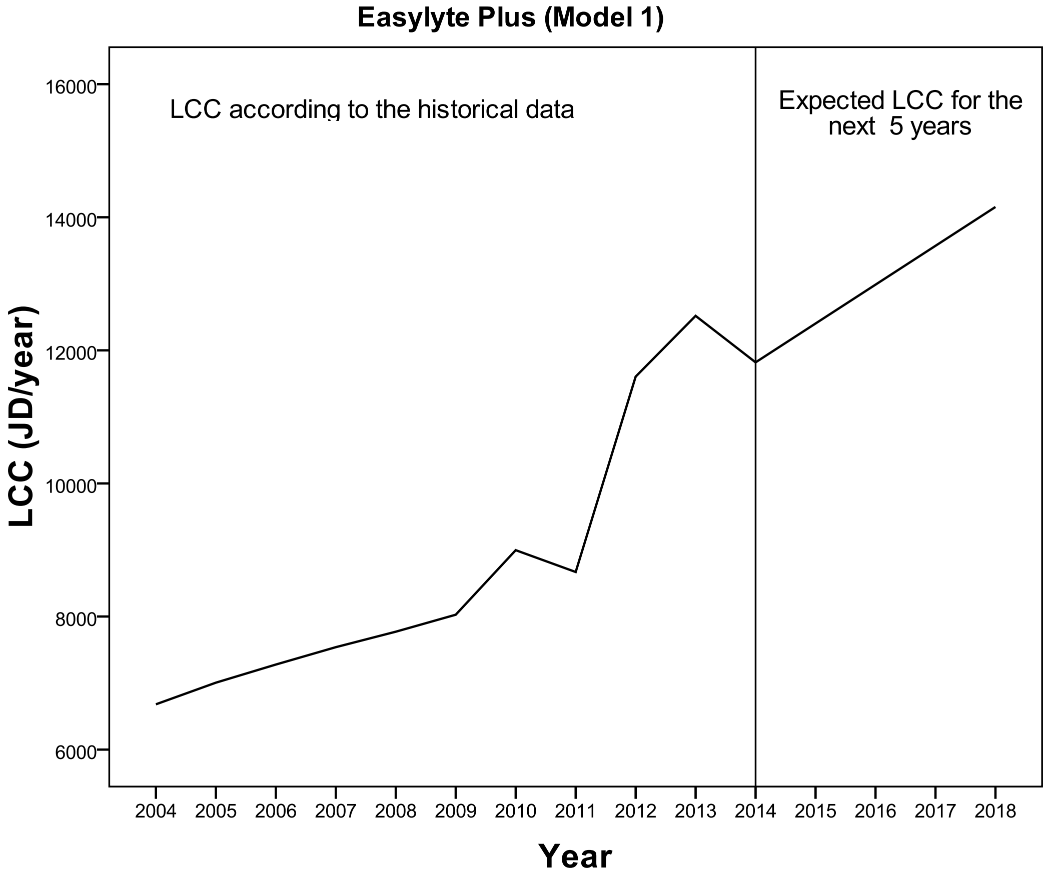


Figure 4.1.9
The previous LCC values from 2004 to 2013 and the future expected values from 2014 to 2018 for Easylyte Plus (Model 1)

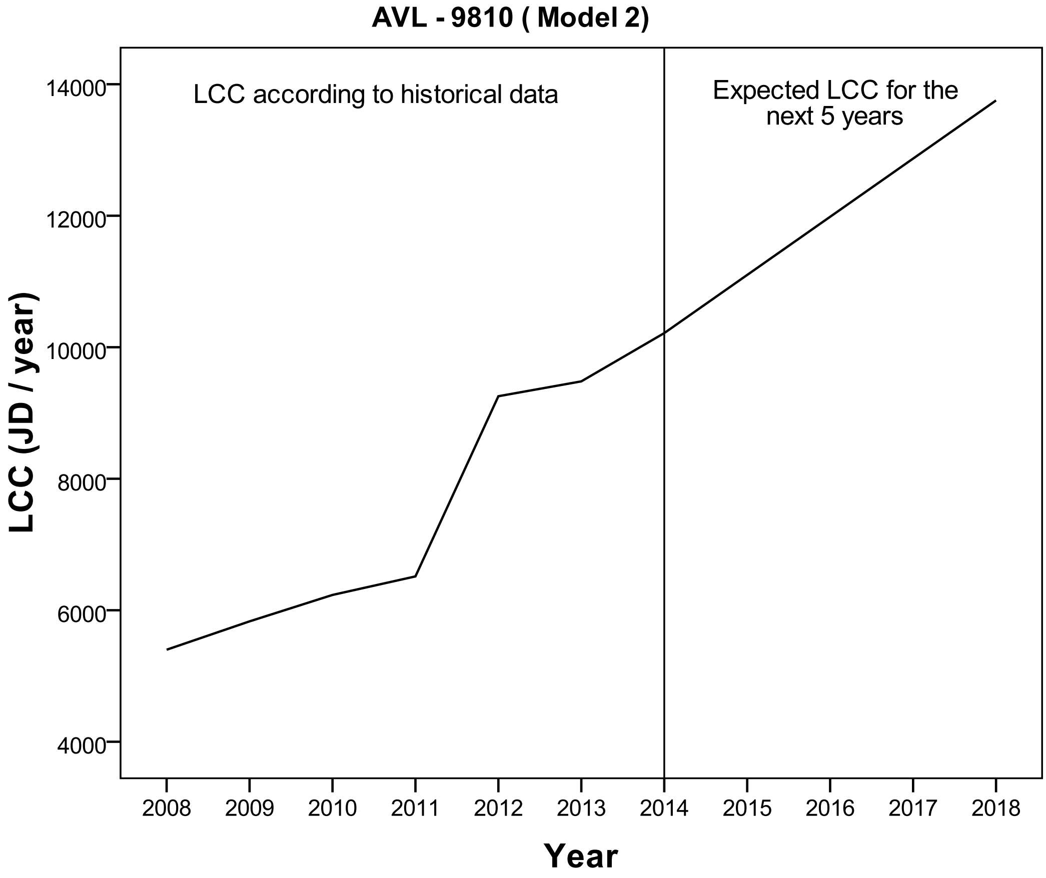


Figure 4.1.10
The previous LCC values from 2004 to 2013 and the future expected values from 2014 to 2018 for AVL – 9810 (Model 2)

4.2 Case Study 2 (X – ray devices):

For the second set of the selected devices, we attempted to compare two models from X-ray devices; namely, UD 150L–30E, Shimadzu, Japan (Model 1) (Shimadzu Corporation, 2000) and KXO-50R, Toshiba, Japan (Model 2)(Toshiba Corporation, 2005). Both Models are diagnostic X- ray devices since they are used to diagnose abnormalities within the body. X-ray images are considered as painless and non-invasive way to detect problems such as broken bones, tumors, dental decay, and the presence of foreign bodies (Encyclopedia of Children's Health, Website [10]). The initial costs for both models are 25,820 JD and 35,000 JD for UD 150L–30E and KXO-50R, respectively. The models are identical in many technical specifications, and consequently, fair comparison could be performed between both models.

Similar methodology was followed in LCC calculations as mentioned in chapter 3 and identical to those applied for the two electrolyte models in section 4.1. After determining the two alternative X- ray models

and collecting required data (i.e., from historical maintenance records, the operators, and the Ministry of Health statistical records), LCC for both X-ray models were estimated using Kaufmann approach (Woodward, 1997).

LCC was estimated for each model and independently for each year during the device service years as follows:

1- Operating Time

According to the operators, UD 150L–30E (Model 1) works during the day shift, while KXO-50R (Model 2) works during the day and with very much less load during night shifts. Therefore, for LCC calculations purposes, the operating time was assumed to be 8 hr per day for both models, and the data were collected only over the day working hours (shift A, from 8 am- 3 pm).

2- Utilization Time

The utilization time for UD 150L–30E is slightly higher than that of KXO-50R due to the slight differences in the required time for each X-ray shoot. The average shoot time was 2.5 and 2.0 sec for UD 150L–30E and KXO-50R, respectively.

The average utilization time / year for UD 150L–30E was 9.61 hr / year, ranging from 8.29 to 11.67 hr / year over the period extended from 2003 to 2013, while the corresponding values for KXO-50R were 8.37 hr / year ranging from 6.68 to 9.33 hr / year over the period extended from 2007 to 2013.

3- The Critical Cost Parameters

Both models showed obviously low MTBF, failure rates and unavailability value.

During the life span of UD 150L–30E for the period extended from 2003 to 2013, failures were only occurred in 5 out of 11 years, with failure rate ranging from 0.02 to 0.045 and average failure rate of 0.009. The availability of UD 150L–30E model was 100% for years without failures, whereas the availability in years combine with failures ranged from 34% to 96 %. Table 4.2.2 shows the critical parameters for UD 150L–30E model.

The second alternative (model KXO-50R) displayed failures during the last two years (2012 and 2013) during its service, with failure rates of 0.053 and 0.02, respectively. The average failure rate of KXO-50R over its whole life span is 0.01. The availability for the first 5 years from installation was 100%, and it was 67% and 95% for the last 2 years of its service respectively. Table 4.2.3

shows the critical parameters for model KXO-50R.

The average MTTR for UD 150 L–30E model was around 15 days, ranging from 1 to 43 days depending on the complicity of the failure (Table 4.2.2). The average MTTR for KXO-50R model was slightly less than that for UD 150 L–30E, which was around 4 days, ranging from 1 to 9 days (Table 4.2.3). These results reflect that the failures of KXO-50R were less complicated than UD 150 L–30E. This parameter also indicates that the maintenance cost is higher for UD 150 L–30E than for KXO-50R during its service. UD 150 L–30E average repair rate over the period extended from 2003 to 2013 was 0.27, which was relatively less than KXO-50R's repair rate (0.51) since the MTTR for UD 150 L–30E is higher than MTTR for KXO-50R.

4- Estimation of the Cost Components:

The initial cost for UD 150 L–30E model is 25,820 JD, which was 26% lower than KXO-50R model initial cost (35, 000 JD).

Total operating cost was calculated by summing up all needed costs to maintain the device working. For UD 150 L–30E, the average operating cost over the device service years was 50,355 JD / year, ranging from 37,573.34 to 74,365.6 JD / year for the period extended from 2003 to 2013 (Table 4.2.4). Operation cost was higher for KXO-50R with an average of 54,901 JD / year, ranging from 38,026.77 to 69,549.04 JD / year (Table 4.2.5). For both models, the operation costs were at its minimum level in 2010 due to the reduction in the working load of the two devices.

The maintenance cost was calculated by summing up all corrective maintenance costs, including the man-hour cost and the cost of the replaced spare parts during the maintenance actions. There were marginal differences between the two models in maintenance cost. The average maintenance cost for Model UD 150 L–30E was 680.17 JD / year. This model had two major maintenance actions that included replacement of expensive major spare parts as compared with KXO-50R model. During 2007 (at the 5th year of the device age), UD 150L–30E model needed major spare parts with a total cost of 1,796 JD. In 2013(at the 11th year of the device age), the cost of the needed spare parts was 5,100 JD. On the other hand, KXO-50R average maintenance cost was 64 JD /year, ranging from 12 to 248.4 JD/ year during its service period. This model exposed to several maintenance actions without the necessity of replacing

major or expensive spare parts as happened for the UD 150L–30E model.

It is obvious that the maintenance cost for the years followed the major maintenance actions were relatively low. Figure 4.2.4 shows the cost of maintenance over the device life.

For UD 150L–30E, the total maintenance cost comprised 29 % from the device initial cost: 20 % is spent during the 11th year (2013) and 7 % at the 5th year (2007) from installation. This might indicate the increase in the maintenance cost by increasing the life time of this particular model and also might indicate the need for major maintenance actions from time to time during its service.

KXO-50R total maintenance cost comprised only 1.28% from the device initial costs, which indicates the privilege of this model as an alternative to UD 150L–30E model in terms of maintenance cost. Tables 4.2.6 and 4.2.7 show the maintenance cost and the percentage of the maintenance cost to the initial cost for UD 150L–30E and KXO-50R models, respectively.

Since the two models works mainly for one shift (8 hours), the income from the two models is incomparable because they have the same number of X-ray exposures and X-ray exposures costs. The marginal differences in income came from the differences in the break down period for each model. And the LCC calculation was concentrated on the costs; therefore the income of the devices was omitted from LCC calculations. Tables 4.2.8 and 4.2.9 show the income of UD 150L–30E and KXO-50R respectively.

1- Based on the inflation and interest rate, the net of all interested cost categories were discounted back to the base period. In this case, the base year was 2007 where all costs were discounted back to this year to compare model UD 150L–30E against model KXO-50R. Tables 4.2.8 and 4.2.9 show the inflation rate and the interest rate as reported from the Jordanian central bank.
2- Summing the discounted costs to establish the net present value and reach LCC. The LCC values will be discussed from the following two point views as previously performed for the Electrolyte models:
3- For each model separately to monitor the yearly costs history over its service years from the installation to 2013, and
4- By discounting back the LCC values to the base year 2007 in order to compare the both models LCC values.

Over the period extended from 2003 to 2013, the average LCC for UD 150L–30E model is 51,034.77 JD / year, ranging from 37,593.34 to 79,639.59JD /year. Table 4.2.8 shows the yearly LCC values over the device service years from 2003 to 2013. Summing up all LCC values over the device service years after discounting them to the installation year released the total LCC values at the year of installation, which is 613,364.7 JD.

KXO-50R LCC yearly values ranged from 38,046.77 to 69,665.74JD / year, with an average of 54,964.57JD / year. The total LCC of the device over its life span (from 2007 to 2013) is 412,722.6 JD / year. Table 4.2.10 shows the LCC values for each model from 2007 to 2013 taking into consideration a discount factor based on year 2007 as a base year. The base year is the first year of having both models in service. This makes the comparison more logical since the money value for each model in the period from 2007 – 2013 were discounted back to the same year.

UD 150 L–30E models displayed 4.4% higher LCC values than KXO-50R when LCC discounted back to 2007. Figure 4.2.5 shows yearly LCC values for both models (Table 4.2.10). Comparing the LCC values for the first four years for both models shows that the LCC values of UD 150L–30E model was relatively lower than the LCC values of KXO-50R model over the first 4 years of their service (Table 4.2.11) because of the differences in power (electrical) costs between the installation years for both models.

These results indicate that KXO-50R model is more preferable alternative for decision makers depending on the LCC values, even though it displayed higher initial cost but lower maintenance cost as compared to UD 150L–30E model.

The released deterministic model for this study case shows that the historical data can be exploited to estimate the LCC values for the coming (x) years of its life. Some statistics were performed for LCC values over years for both models including:

Pearson Correlation Coefficient:

Pearson correlation coefficients (r) were 0.929 and 0.870 between years and LCC values for UD 150L–30E and KXO-50R, respectively (Table 4.2.12). The relation was highly significant at $\alpha = 0.01$. The positive correlation between

LCC and device age indicate that LCC is increasing with the increase of the device age.

Linear Regression:

Linear regression showed significant relationship between LCC and the device age. The regression equations were established for both models and results showed the significant regression between LCC and the device age at α = 0.0001 for both models. The ANOVA table for linear regressing analysis for both models is shown in Table 4.2.13.

A straight line regression model was fitted to the data. The resulting table of regression coefficients is shown in Table 4.2.14. Regression (R^2) for the straight line regression model is 0.864 and 0.922 for UD 150L–30E and KXO-50R, respectively. Figures 4.2.7 and 4.2.8 show scatter plot of LCC against the device age. This means that just over 86.4% and 92.2% of the total variability in LCC has been explained by the straight line regression model for UD 150L–30E and KXO-50R, respectively.

The two representative equations of LCC for both models are:

- LCC equation for UD 150L–30E:
$$LCC(Model\ 1) = 28243.72 + 3798.51\ x$$
- LCC equation for KXO-50R :
$$LCC(Model\ 2) = 33999.34 + \ 5241.309x$$

Where, x represents device age in year(s).These two equations can be used to estimate and evaluate the LCC values over the device future physical life. Applying the device age (x) in these functions for the next five years will give an idea about the devices behavior over years. These values for the following five years are shown in Table 4.2.15.

Figures 4.2.9 and 4.2.10 for UD 150L–30E and KXO-50R, respectively, show that LCC is steadily increased by increasing the device age for both models. The expected average LCC value over the next five years for UD 150L–30E would be 81,422.72 JD /year, whereas LCC expected values would reach the maximum by the year 2018 (LCC = 89,019.72 JD/ year); and the minimum value by 2014(LCC = 73,825.72 JD/ year). Figure 4.2.9 shows the previous LCC values from 2003 to 2013 and the future expected values from

2014 to 2018.

KXO-50R LCC expected values for the next five years would range from 75,929.81JD / year to 96,895.04JD / year with an average would equal 86,412.43JD / year. Figure 4.2.10 shows the previous LCC values from 2007 to 2013 and the future expected values from 2014 to 2018.

Paired t-test:

Paired t-test indicates significantly higher LCC value for UD 150L–30E than KXO-50R suggesting that model 2 KXO-50R. is better alternative than model 1 UD 150L–30E

Taking Decisions on the Better Alternative

The LCC values showed that the total costs for the model 1 UD 150L–30E over its service from 2003 to 2013 as calculated from the historical data were higher than in KXO-50R. Moreover, the LCC values expected from the deterministic model would be higher for the next 5 years.KXO-50R model 2 would need spare parts replacement as its parts would be expired with time and major maintenance actions might be needed as expected from the future LCC values resulted from the deterministic model. The LCC values resulted from the historical data enhances the preference of KXO-50R over UD 150L–30E even though UD 150L–30E displayed lower initial, but model higher maintenance cost over its service year. Therefore it could be concluded that KXO-50R is economically preferred than UD 150L–30E and it is highly recommended for future tenders.

Table 4.2.1
X- ray devices Alternative models specifications

Specification	(Model 1)	(Model 2)
Manufacturer	Shimadzu	Toshiba
Model	UD 150L–30E	KXO-50R
Environmental conditions	(5-40)°C humidity 30% - 85%	(5-40)°C humidity 30% - 85%
Location	Radiology department	Clinic award
Accessories	Operating and service manuals	Operating and service manuals
Installation Date	2003	2007
Required power	3 φ 480V	3 φ 480V
Source	Japan	Japan
operating time	8 hr/ day	24 hr/ day
Initial cost JD	25820	35000

Table 4.2.2
Critical cost parameters for UD 150L–30E, Shimadzu, Japan (Model 1) as calculated from historical data

Critical cost parameter	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mean time between failures yearly (MTBF)	/*	/*	/*	/*	22	/*	49.667	/*	/*	/*	32.8
Mean time to repair (MTTR)	/*	/*	/*	13	43.3	4	4.75	/*	/*	1	21.8
Failure Rate (λ)	0	0	0	0	0.045	0	0.02	0	0	0	0.03
Repair Rate (μ)	0	0	0	0.077	0.023	0.25	0.211	0	0	1	0.046
Device availability (%)	100	100	100	96.44	33.6	98.9	91.27	100	100	99.99	60.07
Device unavailability (%)	0	0	0	3.56	66.4	1.1	8.73	0	0	0.01	39.93

*No failures had occurred.

Table 4.2.3
Critical cost parameters for KXO-50R, Toshiba, Japan (Model 2) as calculated from historical data

Critical cost parameter	Year						
	2007	2008	2009	2010	2011	2012	2013
Mean time between failures yearly (MTBF)	/*	/*	/*	/*	/*	19	50
Mean time to repair (MTTR)	/*	/*	/*	/*	1	9.22	2.4
Failure Rate (λ)	0	0	0	0	0	0.053	0.02
Repair Rate (μ)	0	0	0	0	1	0.108	0.417
Device availability %	100	100	100	100	99.9	67.32	95.42
Device unavailability %	0	0	0	0	0.01	32.68	4.58

*No failures had occurred.

Table 4.2.4

The operating cost for UD 150L–30E, Shimadzu, Japan (Model 1) as collected from operators and historical records

Operation category	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
No. of X- ray shoots have been performed in a year	11933	11955	12231	12241	12032	12032	15953	14770	16803	15890	16346
No. of films have been consumed in a year	12869	13436	14628	13050	14244	13025	16520	14850	17100	15918	16350
The total cost of films in a year	25738	26871	29256	26102	28487	26050	33041	29700	34200	31836	32700
The man-hour cost for the operator JD	2050	2065	2080	2095	2110	2125	2140	2155	2170	3820	3835
The cost of each X – ray shoot JD	3	3	3	3	3	3	5	5	5	5	5
The no. of breakdown days / years	0	0	0	13	130	4	19	0	0	1	109
The cost of the break down period JD / year	0	0	0	1308	12856.54	395.56	4152.18	0	0	217.67	24407.37
The income of the device.	35799.3	35865	36693	35415	23240.66	35701.61	75613.32	73848	84013.5	79232.83	57324.36
No. of utilizing hours in a year	8.29	8.30	8.49	8.5	8.36	8.36	11.08	10.26	11.67	11.03	11.35
The energy consumed in a year (K watt)	119331	119550	122310	122410	120324	120324	159531	147696	168027	158901	163464
The average cost of the consumed power Fills/ KW*	0.082	0.082	0.082	0.082	0.082	0.113	0.113	0.114	0.144	0.205	0.235
Total electrical cost(JD)	9785.142	9803.1	10029.42	10037.62	9866.57	13596.612	18027	16837.34	24195.89	32495.25	38414.04
The total operating cost	37573.34	38739.1	41365.42	41388.62	41232.57	44977.612	53207.80	53382.33	58183.26	69484.89	74365.59
The % of the operating cost to the capital cost	145.52	150	160	160	159.69	174	206	206.75	225	269	288

Table 4.2.5
The operating cost for KXO-50R, Toshiba, Japan (Model 2) as collected from the operators and historical records

Operation category	Year						
	2007	2008	2009	2010	2011	2012	2013
No. of X- ray shoots have been performed in a year	12032.4	13716.3	15953.1	14769.6	16802.7	15890.1	16346.4
No. of films have been consumed in a year	13025.1	14243.7	16520.4	14850	17100	15918	13650
The total cost of films in a year	26050.2	28487.4	33040.8	29700	34200	31836	
The man-hour cost for the operator JD	2110	2125	2140	2155	2170	3820	3835
The cost of each X – ray shoot JD	3	3	5	5	5	5	5
The no. of breakdown days / years	0	0	0	0	1	83	12
The cost of the break down period JD / year	0	0	0	0	230.17	18066.83	2687.08
The income of the device.	36097.2	41148.9	79765.5	73848	83783.33	61383.67	79044.92
No. of utilizing hours in a year	6.68	7.62	8.86	8.21	9.33	8.83	9.08
The energy consumed in a year (K watt)	120324	137163	159531	147696	168027	158901	163464
The average cost of the consumed power Fills/ KW*	0.082	0.113	0.113	0.114	0.144	0.2045	0.235
Total electrical cost(JD)	9866.57	15499.42	18027	16837.34	24195.89	32495.26	38414.04
The total operating cost	38026.768	46111.82	53207.80	48692.34	60565.89	68151.25	69549.04
The % of the operating cost to the capital cost	216.52	262.55	302.95	277.24	344.85	388.04	396

Table 4.2.6

The maintenance cost for UD 150L–30E, Shimadzu, Japan (Model 1) as collected from the operators and historical records

Maintenance category	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Corrective maintenance											
• Spare parts cost	0	0	0	12	1795.68	0	25	0	0	0	5100
• Man-hour cost	0	0	0	29.6	79.2	14	122.4	0	0	6	162
Preventive Maintenance											
• Spare parts cost	0	0	0	0	0	0	0	0	0	0	0
• Man-hour cost	20	20	12	12	12	12	12	12	12	12	12
Total maintenance cost	20	20	12	53.6	1886.88	26	159.4	12	12	18	5274
%Maintenance cost related to the capital cost	0.077	0.077	0.046	0.161	7.31	0.101	0.617	0.046	0.046	0.069	20.43

Table 4.2.7

The maintenance cost for KXO-50R, Toshiba, Japan (Model 2) as collected from the operators and historical records

Maintenance Category	Year						
	2007	2008	2009	2010	2011	2012	2013
Corrective maintenance							
• Spare parts cost	0	0	0	0	0	0	1.497
• Man-hour cost	0	0	0	0	6	236.4	103.2
Preventive Maintenance							
• Spare parts cost	0	0	0	0	0	0	0
• Man-hour cost	20	20	12	12	12	12	12
Total maintenance cost	20	20	12	12	18	248.4	116.697
%Maintenance cost related to the capital cost	0.114	0.114	0.068	0.068	0.102	1.41	0.664

Table 4.2.8
The costs summery for UD 150L–30E, Shimadzu, Japan (Model 1) as calculated from the collected data from the operators and historical records

Cost category	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
The capital cost.	25820	23238	20914.2	18822.8	16940.5	15246.45	13721.81	12349.63	11114.66	10003.2	9002.88
The total operating cost (JD).	37573.3	38739.1	41365.42	41388.6	41232.57	44977.61	53207.803	53382.334	58183.264	69484.89	74365.59
The % of the operating cost to the capital cost.	145.52	150	160	160	159.69	174	206	206.75	225	269	288
Total maintenance cost	20	20	12	41.6	1886.88	26	159.4	12	12	18	5274
% of total maintenance cost.	0.077	0.077	0.046	0.161	7.31	0.101	0.617	0.046	0.046	0.069	20.43
The salvage value (JD).	25820	23238	20914.2	18822.8	16940.5	15246.45	13721.81	12349.63	11114.66	10003.2	9002.88
The income of the device/ year.	37593.3	38759.1	41377.42	41430.2	43119.45	45003.61	53367.20	53394.33	58195.26	69502.89	79639.59
The inflation rate (%).	1.6	2.6	3.5	6.25	4.7	13.9	-0.7	4.48	4.15	4.42	5.29
The interest rate (%).	2.75	2.49	3.52	5.13	5.56	5.66	4.23	3.4	3.46	4.19	4.97
LCC (JD).	37593.34	38759.1	41377.42	41430.2	43119.45	45003.61	53367.20	53394.33	58195.26	69502.89	79639.59

Table 4.2.9

The costs summery KXO-50R, Toshiba, Japan (Model 2) as calculated from the collected historical data and the operators

Cost Category	Year						
	2007	2008	2009	2010	2011	2012	2013
The capital cost.	35000	9447.84	10497.6	11664	12960	14400	16000
The total operating cost (JD).	38026.77	46111.82	53207.80	48692.34	60565.89	68151.25	69549.04
The % of the operating cost to the capital cost.	109	132	152	139	173	195	199
The total maintenance cost (JD).	20	20	12	12	18	248.4	116.697
The % of the total maintenance cost.	0.057	0.057	0.034	0.034	0.051	0.709	0.333
The salvage value (JD).	35000	9447.84	10497.6	11664	12960	14400	16000
The income of the device/ year.	36097.2	41148.9	79765.5	73848	83783.33	61383.67	79044.92
The inflation rate (%).	4.7	13.9	-0.7	4.48	4.15	4.42	5.29
The interest rate (%).	5.56	5.66	4.23	3.4	3.46	4.19	4.97
LCC (JD / year).	38046.77	46131.82	53219.8	48704.34	60583.89	68399.65	69665.74

Table 4.2.10

Discounted LCC values for both X- ray models, UD 150L–30E , Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2) , over the years 2007- 2013

Model	Year						
	2007	2008	2009	2010	2011	2012	2013
UD 150L–30E (Model 1)	43119.45	48689.049	49840.2117	57132.0165	61027.5071	69870.1342	86799.7892
KXO-50R (Model 2)	38046.77	49909.65	49702.55	52113.72	63532.38	68761.07	75929.22

Table 4.2.11

Discounted LCC values for both X- ray models, UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2), regarding to each model age

Model	Device age (year)			
	1	2	3	4
UD 150L–30E (Model 1)	35938.38	38884.03	40488.5	41119.01
KXO-50R (Model 2)	38046.77	49909.65	49702.55	52113.72

Table 4.2.12
Results of correlations for both models as obtained from SPSS17.0 program

		Year	UD 150L–30E (Model 1)	KXO-50R (Model 2)
Year	Pearson Correlation	1	0.929	0.870
	Sig.(1-tailed)		0.0001	0.005
	N	11	11	7
UD 150L–30E (Model 1)	Pearson Correlation	0.929	1	0.960
	Sig.(1-tailed)	0.0001		0.001
	N	11	11	7
KXO-50R (Model 2)	Pearson Correlation	0.870	0.960	1
	Sig.(1-tailed)	0.005	0.001	
	N	7	7	7

Table 4.2.13
Results of ANOVA regression analyes as obtained from SPSS17.0 program

	Sum of squares	Degrees of freedom (df)	Mean square	F	Significance level (α)
		UD 150L–30E (Model 1)			
Regression	1.587×10^9	1	1.587×10^9	57.061	0.0001
Residual	2.503×10^8	9	2.782×10^7		
Total	1.837×10^9	10			
		KXO-50R (Model 2)			
Regression	7.692×10^8	1	7.692×10^8	58.745	0.001
Residual	6.547×10^7	5	1.309×10^7		
Total	8.347×10^8	6			

Table 4.2.14
Results of regression coefficients for both models as obtained from SPSS17.0 program

	Unstandardized Coefficients		Standardized Coefficients		
	C	Std. Error	Beta	t-value	Sig.
			UD 150L–30E (Model 1)		
(Constant) (A)	28243.717	3410.548		8.281	0.0001
device age(B)	3798.508	502.858	0.929	7.554	0.0001
			KXO-50R (Model 2)		
(Constant) (A)	33999.336	3058.235		11.117	0.0001
device age(B)	5241.309	683.842	0.960	7.665	0.001

Table 4.2.15
The expected LCC values for the next 5 years (2014 to 2018)

Year	Model	
	UD150L–30E (Model 1)	KXO-50R (Model 2)
2014	73825.81	75929.81
2015	77624.32	81171.12
2016	81422.83	86412.43
2017	85221.34	91653.74
2018	89019.85	96895.04

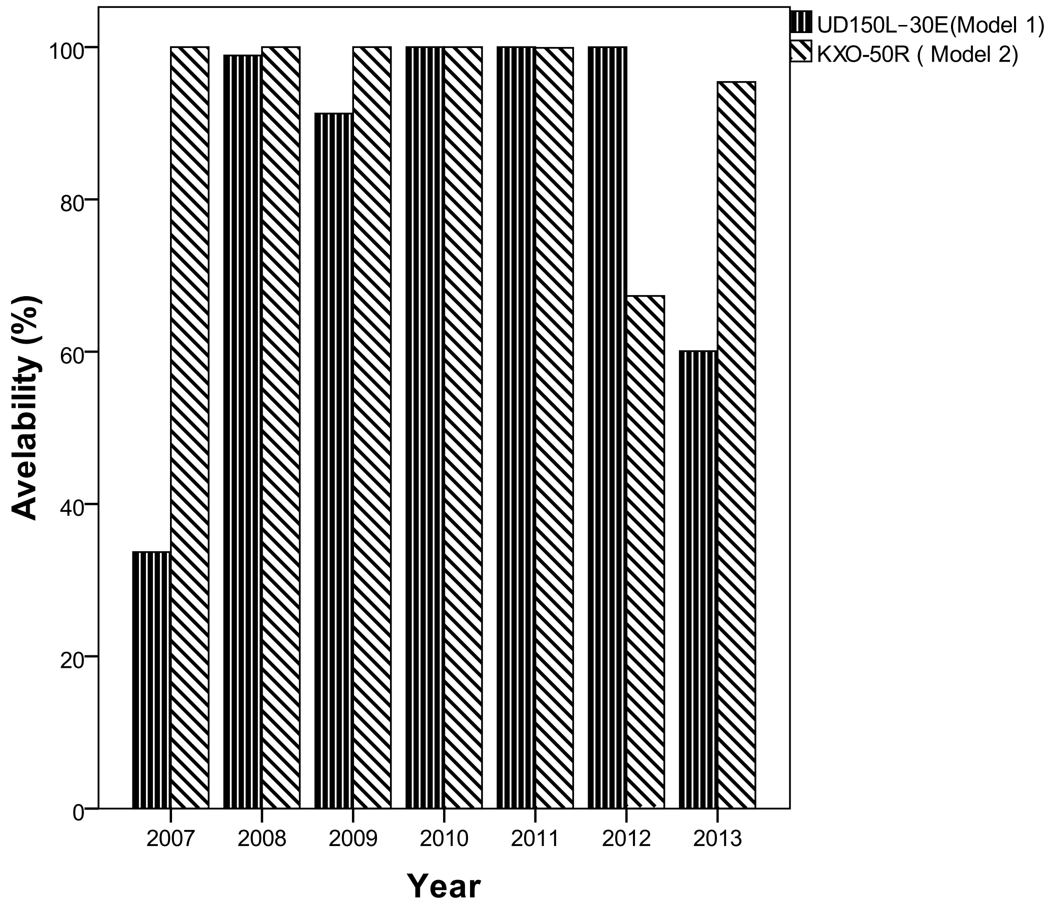


Figure 4.2.1

The availability % for the two X-Ray models: UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2)

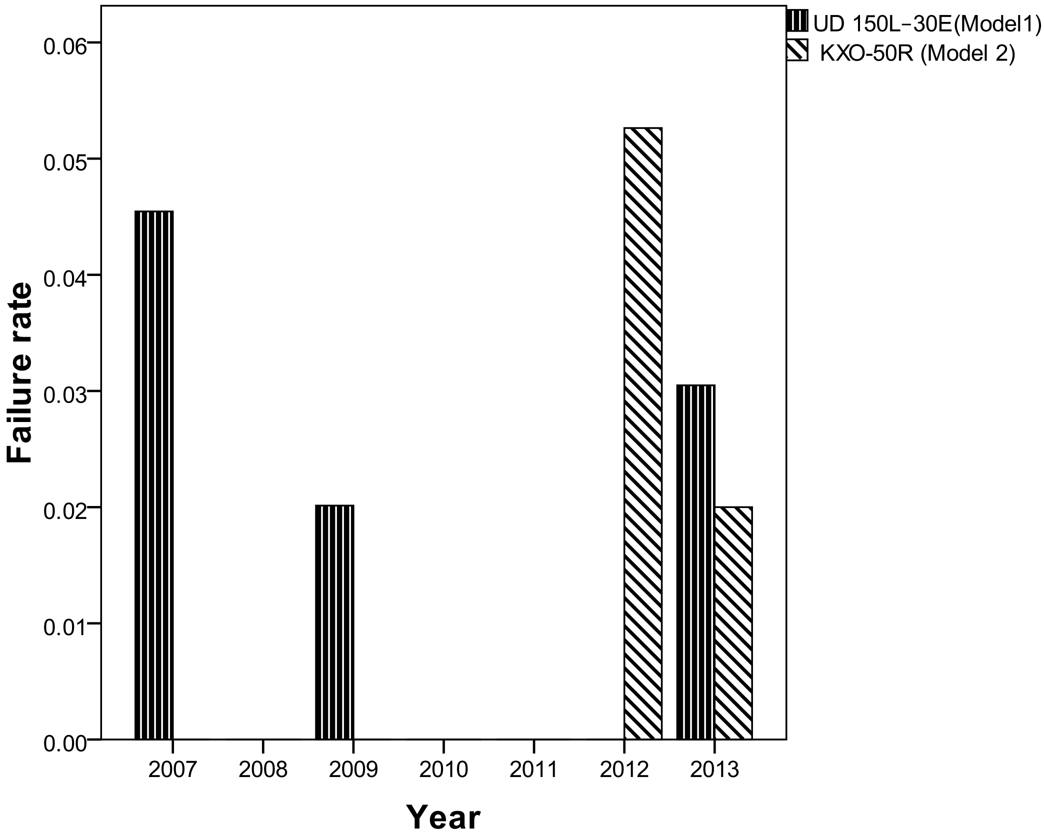


Figure 4.2.2
The failure rate for the two X-Ray models: UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2)

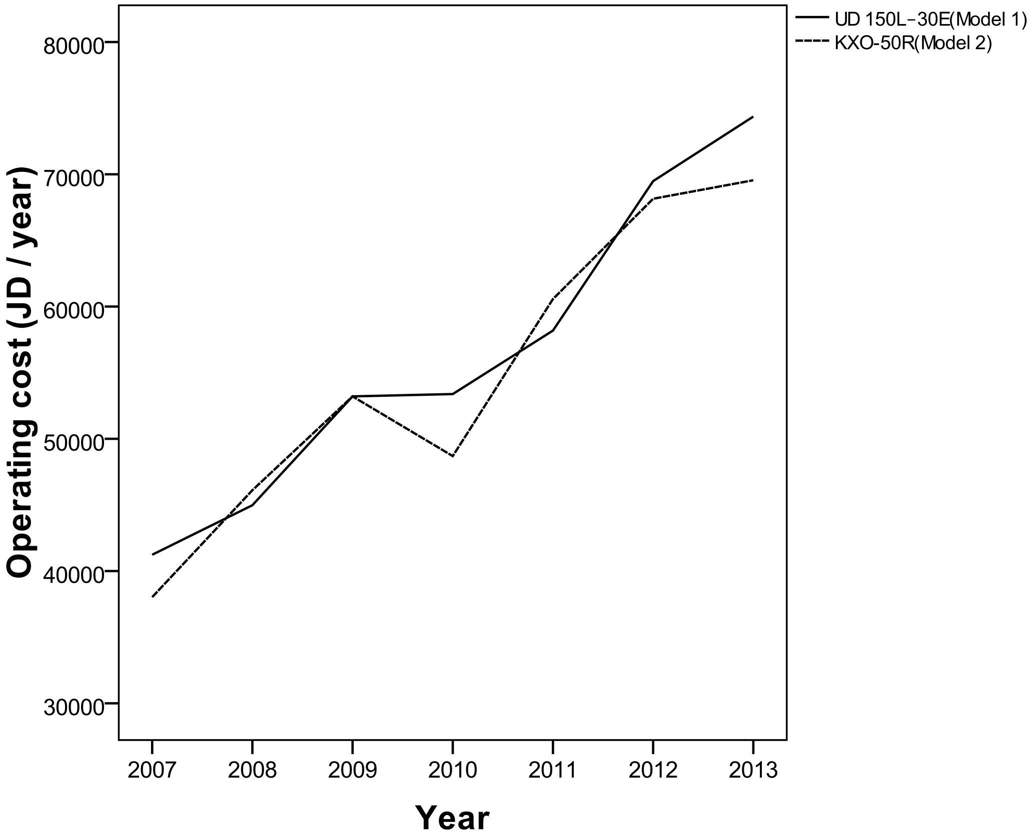


Figure 4.2.3
The operation cost for the two X-Ray models: UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2)

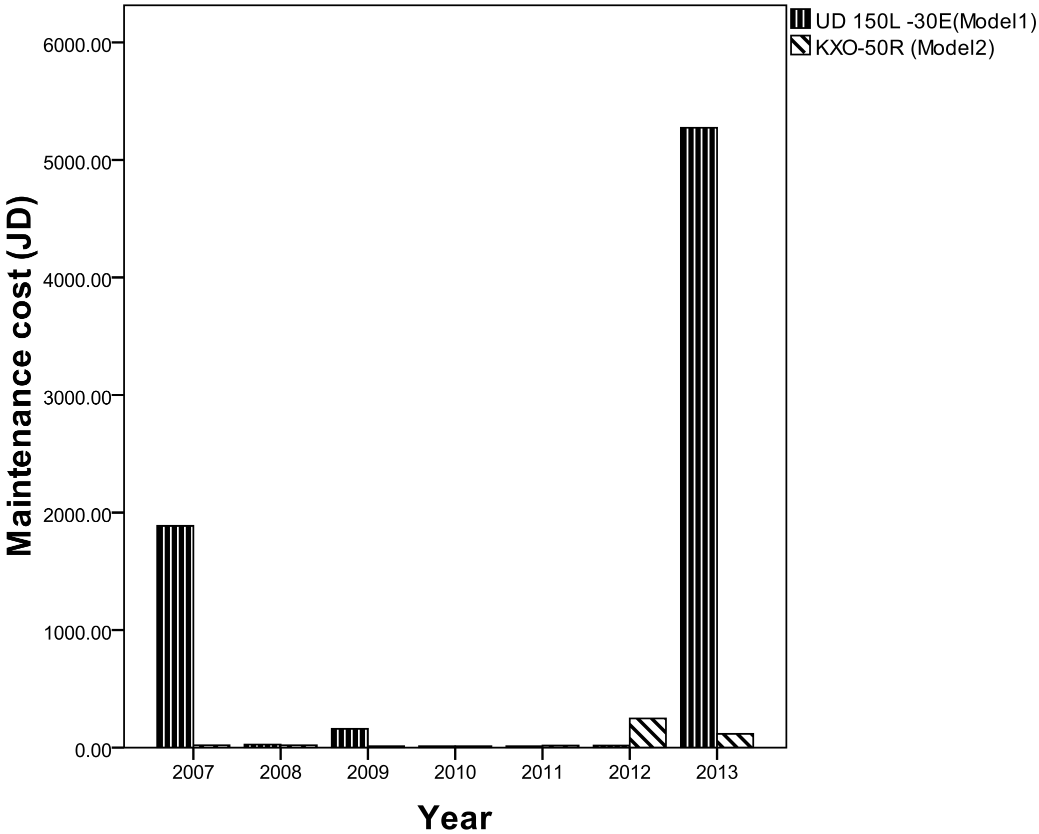


Figure 4.2.4

The maintenance cost for the two X-Ray models: UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2)

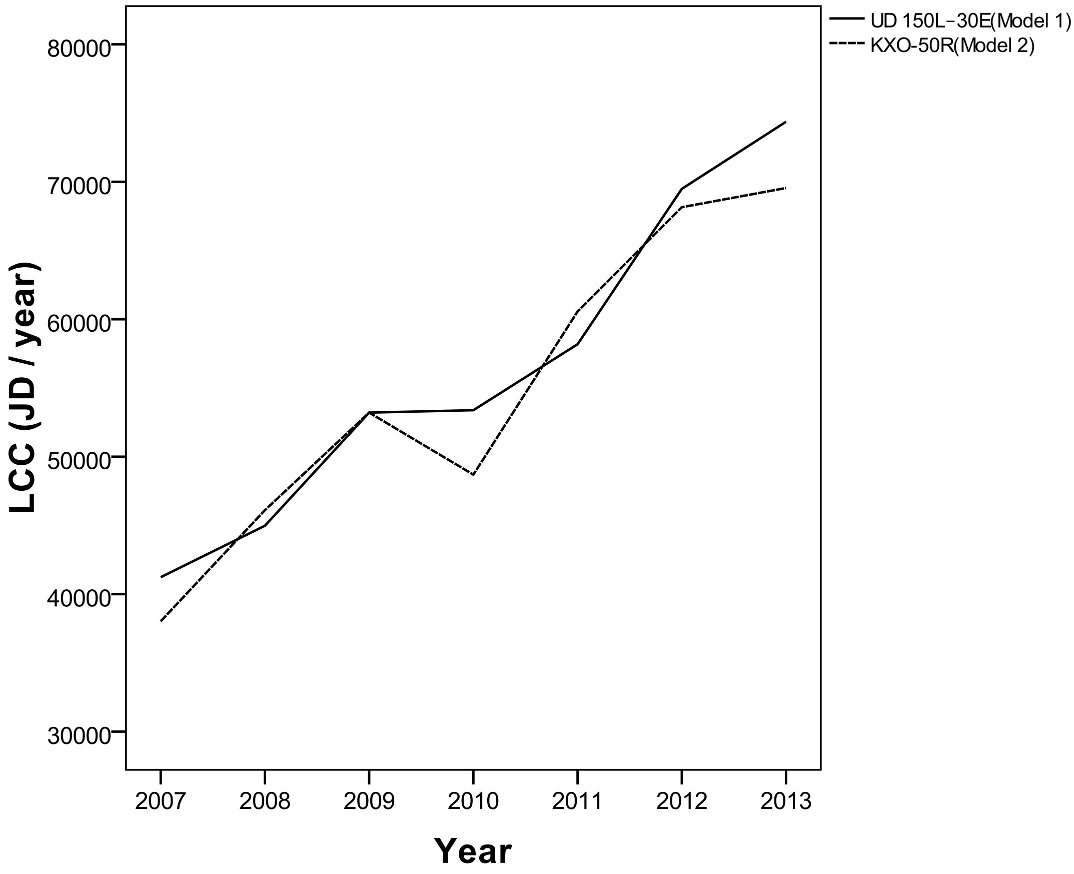


Figure 4.2.5
The LCC for the two X-ray models: UD 150L–30E, Shimadzu, Japan (Model 1) and KXO-50R, Toshiba, Japan (Model 2)

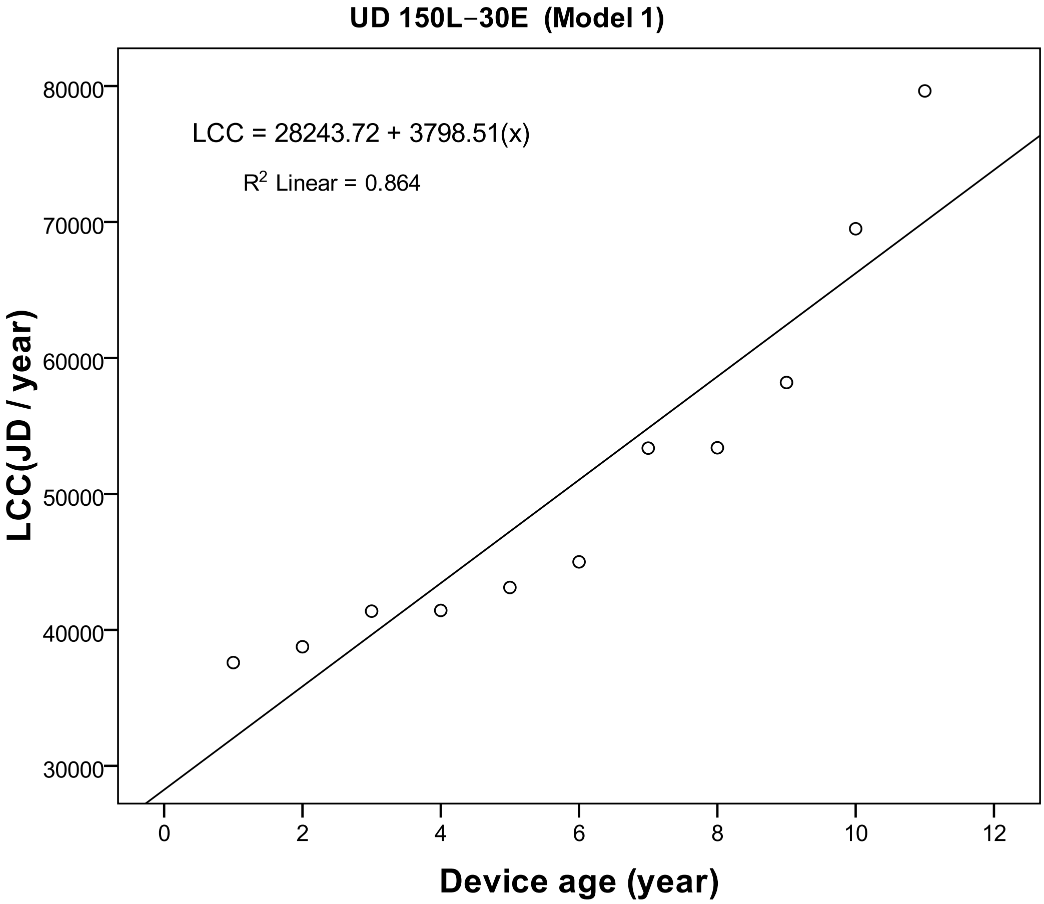


Figure 4.2.6
Scatter plot of LCC against the device age, together with a straight line regression for UD 150L–30E, Shimadzu, Japan (Model 1)

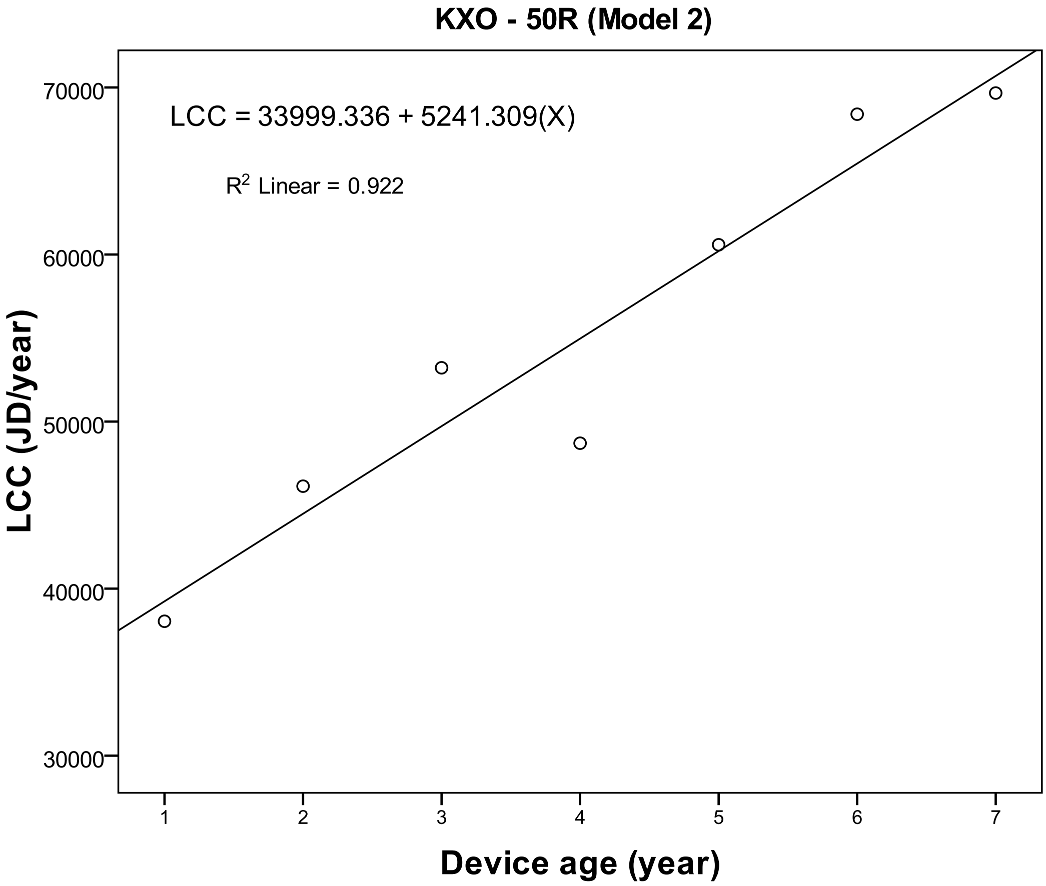


Figure 4.2.7
Scatter plot of LCC against the device age, together with a straight line regression for KXO-50R, Toshiba, Japan (Model 2)

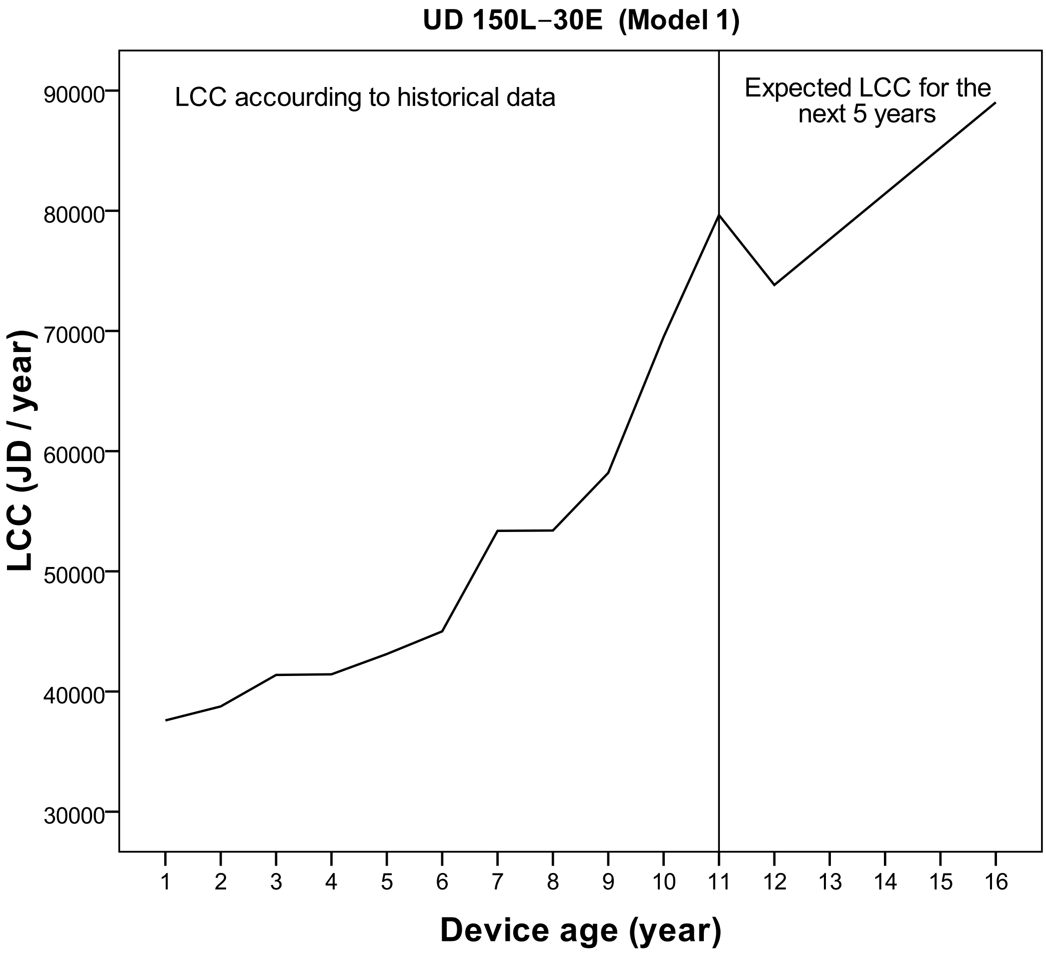


Figure 4.2.8
The previous LCC values from 2004 to 2013 and the future expected values from 2014 to 2018 for UD 150L–30E, Shimadzu, Japan (Model 1)

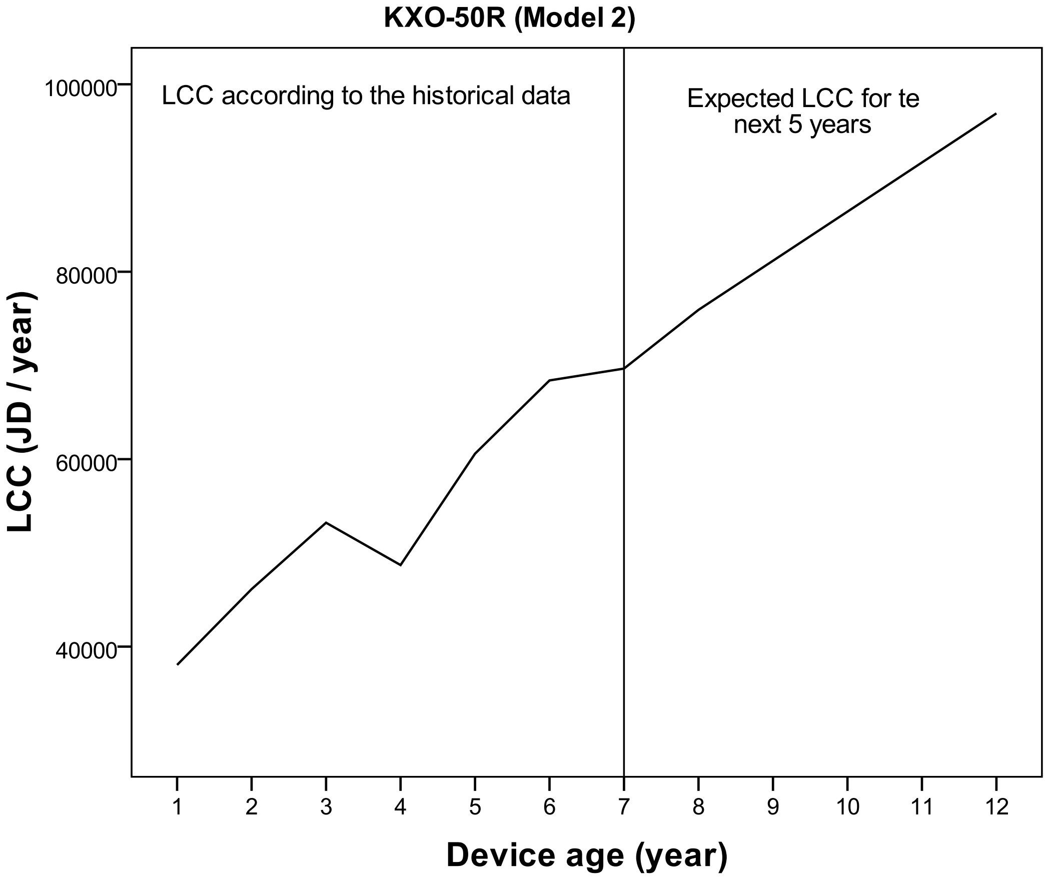


Figure 4.2.9
The previous LCC values from 2004 to 2013 and the future expected values from 2014 to 2018 for KXO-50R, Toshiba, Japan (Model 2)

4.3 Case Study 3 (Infant Incubator Devices):

For the third set of the selected devices, two models from infant incubator devices were compared; namely, Air shields C450, Vickers PLC Company, UK (Model 1) (Vickers company PLC, 2000) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2) (Guido-Rayos-X.SA, 2002). Both Models are generally used to provide a safe and stable environment for newborn infants, often those who were born prematurely or with an illness or disability that makes them especially vulnerable for the first several months of life (Web site [11]). The initial costs for both models are 4,600 JD and 5,000 JD for Air shields C450 (Model 1) and Nestoret 5050 (Model 2), respectively. The models specifications are shown in Table 4.3.1.

Similar methodology was followed in LCC calculations as mentioned in chapter 3 and identical to those applied for the two study cases in sections 4.1 and 4.2. After determining the two alternative infant

incubator models and collecting required data (i.e., from historical maintenance records, the operators, and the Ministry of Health statistical records), LCC for both models were estimated using Kaufmann approach (Woodward, 1997).

LCC was estimated for each model and independently for each year during the device service years as follows:

1- Operating and Utilization Time

The operating time and utilization time are assumed to be similar since infant incubators work for 24 hr per day for seven days per week for both models.

2- The critical cost parameters

During the life span of Air shields C450 for the period extended from 2005 to 2013, the average failure rate was 0.011 and the availability was 88% (Table 4.3.2). The corresponding values for Nestoret 5050 were comparably higher for average failure rate (0.024) and lower for availability (83.4%) for the period extended from 2003 to 2013 (Table 4.3.3). Figures 4.3.1 and 4.3.2 represents the availability and failure rate for both models.

3- Estimation of the cost components:

The initial cost for Air shields C450 model is 4600 JD and 5000 JD for Nestoret 5050. Figure 4.3.3 shows the operating cost for both models over years. For Air shields C450, the average operating cost over the device service years was 6090 JD / year (Table 4.3.4), which was lower than that calculated for Nestoret 5050 with an average of 6316.5 JD / year (Table 4.3.5).

The average maintenance cost for Air shields C450 was 30 JD / year, ranging from 8 to 60 JD (Table 4.3.6). The average maintenance cost for Nestoret 5050 was 78 JD /year, ranging from 8 to 374 JD/ year during its service period (Table 4.3.7). also the maintenance cost is presented graphically in Figure 4.3.4

Since the two models works have the same utilization time and the same number of patients per year, it has been assumed that the income from the two models is similar. As the income values are so close, the LCC calculation was concentrated on the costs, and therefore, the income of the devices was omitted from LCC calculations. Tables 4.3.8 and 4.3.9 show the income of Air shields C450 and Nestoret 5050, respectively.

Over the period extended from 2005 to 2013, the average LCC for Air shields C450 model is 6120.58 JD / year, ranging from 5548.41 to 6737.64 JD /year (Table 4.3.10). The total LCC over its service years (for 9 years) is 60,255.92 JD. Nestoret 5050 yearly values ranged from 5338.52 to 7042.46 JD / year, with an average of 6241.62 JD / year. The total LCC of the device over its service (2003-2013) is 75,987.1 (Table 4.3.10). These results indicate that Shields C450 model is more preferable alternative for decision-making depending on the LCC values, with lower initial and lower maintenance cost

as compared to Nestoret 5050 model and 5% lower in LCC values. Figure 4.3.6 shows the LCC values for both models over years.

Similarly, the regression analysis can be exploited to estimate the LCC values for the two infant incubator models for the coming (x) service years. Some statistics were performed for LCC values over years for both models including:

Pearson correlation coefficient:

Pearson correlation coefficients (r) were 0.98 and 0.961between years and LCC values for Air Shields C450 and Nestoret 5050, respectively (Table 4.3.12). This positive significant correlations ($\alpha = 0.01$) indicate that LCC is increasing with the increase of the device age.

Linear regression:

The regression between LCC and device age were significant ($\alpha = 0.0001$) for both models. The ANOVA table for linear regressing analysis for both models is shown in Table 4.3.13. Regression (R^2) for the straight line regression model is 0.959 and 0.923 for Air Shields C450 and Nestoret 5050, respectively (Figures 4.3.7 and 4.3.8 respectively)

The two representative equations of LCC for both models are:

- LCC equation for Air Shields C450:

$$LCC(Model\ 1) = 5355.68 + 152.98x$$

- LCC equation for Nestoret 5050:

$$LCC(Model\ 2) = 5321.84 + \ 153.29x$$

Where, *x* represents device age in year(s).The expected LCC for the next five years are shown in Table 4.3.15.

The expected ranged LCC values over the next five years for Air Shields C450 would be 6885.47 in 2014 to7161.39 JD /year in 2018. Figure 4.3.9 shows the estimated LCC values from 2005 to 2013 and the expected LCC values from 2014 to 2018. Similarly, the expected LCC values for the next five years for Nestoret 5050 will be continuously increased from 7497.39 JD/year in 2014 to 7774.58 JD/year in 2018. Figure 4.3.10 shows the previous LCC values from 2003 to 2013 and the future expected values from 2014 to 2018.

Paired t-test:

Paired t-test indicates significantly higher LCC value for Nestoret 5050 than Air Shields C450 pointing that Air Shields C450 is better alternative than Nestoret 5050.

Taking decisions on the better alternative

The LCC values showed that the total costs for Nestoret 5050 over its service were higher than Air Shields C450. Moreover, the LCC values expected from the deterministic model would be higher for the next 5 years. Therefore it could be concluded that Air Shields C450 is better economic alternative as compared to Nestoret 5050.

Table 4.3.1
Infant incubator devices alternative models specifications

Specification	(Model 1)	(Model 2)
Manufacturer	Vickers PLC company	Guido Rayos X, S.A.
Model	Air shields C450	Nestoret 5050
Environmental conditions	20 - 30°C 5-95 % humidity	20 - 30°C 5-95 % humidity
Noise level within hood environment	< 49 dBA	< 49 dBA
Dimensions(high * width * depth) (cm^3)	140*116*56	131*90*59
Weight	76 KG	77 KG
Installation Date	2005	2003
Required power	220 V	220 V
Source	USA	Spain
operating time	24 hr / day	24 hr/ day
Initial cost JD	4600	5000

Table 4.3.2

Critical cost parameters for Air shields C450, Vickers PLC Company, (Model 1) as calculated from historical data

*No failures had occurred.

Critical cost parameter	Year								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mean time between failures yearly (MTBF)	/*	81	20.67	/*	65.75	51.25	/*	/*	/*
Mean time to repair (MTTR)	/*	19.5	3.33	/*	8.75	1	223	1	/*
Failure Rate (λ)	0	0.0123	0.04838	0	0.01521	0.0195	0	0	0
Repair Rate (μ)	0	0.0513	0.3003	0	0.11429	1	0.0045	1	0
Device availability (%)	100	81	86	100	88	98	39	99	100
Device unavailability (%)	0	19	14	0	12	2	61	1	0

Table 4.3.3
Critical cost parameters for Nestoret 5050, Guido Rayos X.SA, Spain (Model 2) as calculated from historical data

Critical cost parameter	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Mean time between failures yearly (MTBF)	38.5	/*	221.67	15	6	/*	/*	/*	/*	/*	/*
Mean time to repair (MTTR)	3.5	0	2.166667	87.66667	43	0	0	0	0	0	0
Failure Rate (λ)	0.025974	0	0.004511	0.066667	0.166667	0	0	0	0	0	0
Repair Rate (μ)	0.285714	/*	0.461538	0.011407	0.023256	/*	/*	/*	/*	/*	/*
Device availability %	92	100	99	15	12	100	100	100	100	100	100
Device unavailability %	8	0	1	85	88	0	0	0	0	0	0

*No failures had occurred.

Table 4.3.4
The operating cost for Air shields C450, Vickers PLC Company, (Model 1) as collected from operators and historical records

Operation category	Year								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
No. of babies have admitted to the infant incubator in a year	52	44	49	59	49	47	43	57	56
No. of device occupation days	312	308	245	354	280	399	301	329	294
The revenue of the device	31200	30800	24500	35400	28000	39900	30100	32900	29400
The no. of breakdown days	0	39	10	0	35	4	223	1	0
The cost of the break down period	0	3900	1000	0	3500	400	22300	100	0
Device Income	31200	26900	23500	35400	24500	39500	7800	32800	29400
The manhour cost for the operator	5160	5280	5400	5520	5640	5760	5880	6000	6120
No. of utilizing hours in a year hr / year	7488	7392	5880	8496	6720	9576	7224	7896	7056
The energy consumed in a year (K watt)	4492.8	4435.2	3528	5097.6	4032	5745.6	4334.4	4737.6	4233.6
The average cost of the consumed power JD / KW**	0.082	0.082	0.082	0.082	0.082	0.113	0.113	0.114	0.144
Total electrical cost(JD)	368.41	363.6864	289.29	418	330.62	649.25	489.79	540.09	609.64
The total operating cost	5528.41	5643.69	5689.29	5938	5970.62	6409.25	6369.79	6540.09	6729.64
The % of the operating cost to the capital cost	120	123	124	129	130	139	138	142	146

Table 4.3.5
The operating cost for Nestoret 5050, Guido Rayos X.SA, Spain (Model 2) as collected from the operators and historical records

Operation category	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
No. of babies have admitted to the infant incubator in a year	45	48	52	44	49	59	56	57	43	47	49
No. of device occupation days	225	336	312	308	245	354	280	399	301	329	294
The revenue of the device	22500	33600	31200	30800	24500	35400	28000	39900	30100	32900	29400
The no. of breakdown days	7	0	13	260	86	0	0	0	0	0	0
The cost of the break down period	700	0	1300	26000	8600	0	0	0	0	0	0
Device Income	21800	33600	29900	4800	15900	35400	28000	39900	30100	32900	29400
The manhour cost for the operator	4920	5040	5160	5280	5400	5520	5640	5760	5880	6000	6120
No. of utilizing hours in a year hr / year	5400	8064	7488	7392	5880	8496	6720	9576	7224	7896	7056
The energy consumed in a year (K watt)	4860	7257.6	6739.2	6652.8	5292	7646.4	6048	8618.4	6501.6	7106.4	6350.4
The average cost of the consumed power JD / KW**	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.113	0.113	0.114	0.144
Total electrical cost(JD)	398.52	595.12	552.61	545.53	433.94	627.0	496	973.88	734.68	810.13	914.46
The total operating cost	5318.52	5635.12	5712.61	5825.53	5833.94	6147.0	6135.94	6733.88	6614.68	6810.13	7034.46
The % of the operating cost to the capital cost	106	113	114	117	117	123	123	135	132	136	141

Table 4.3.6
The maintenance cost for Air shields C450, Vickers PLC Company, (Model 1) as collected from the operators and historical records

Maintenance Category	Year								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
Corrective maintenance									
• Spare parts cost	0	0	0	0	0	0	0	0	0
• Man-hour cost	0	40	24	0	40	42.4	10	14	0
Preventive Maintenance									
• Spare parts cost	0	0	0	0	0	0	0	0	0
• Man-hour cost	20	20	8	8	8	8	8	8	8
Total maintenance cost	20	60	32	8	48	50.4	18	22	8
%Maintenance cost related to the capital cost	0.435	1.304	0.695	0.174	1.043	1.09	0.391	0.478	0.174

Table 4.3.7

The maintenance cost for Nestoret 5050, Guido Rayos X.SA, Spain (Model 2) as collected from the operators and historical records

Maintenance category	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Corrective maintenance											
• Spare parts cost	0	0	0	330	350	0	0	0	0	0	0
• Man-hour cost	12	0	36	24	16	0	0	0	0	0	0
Preventive Maintenance											
• Spare parts cost	0	0	0	0	0	0	0	0	0	0	0
• Man-hour cost	8	8	8	8	8	8	8	8	8	8	8
Total maintenance cost	20	8	44	362	374	8	8	8	8	8	8
%Maintenance cost related to the capital cost	0.4	0.16	0.88	7.24	7.48	0.16	0.16	0.16	0.16	0.16	0.16

Table 4.3.8

The costs summery Air shields C450, Vickers PLC Company, (Model 1) as calculated from the collected historical data and the operators

Cost Category	Year								
	2005	2006	2007	2008	2009	2010	2011	2012	2013
The capital cost.	4600	4140	3726	3353.4	3018.06	2716.25	2444.63	2200.17	1980.15
The total operating cost (JD).	5528.41	5643.69	5689.29	5938	5970.62	6409.25	6369.79	6540.09	6729.64
The % of the operating cost to the capital cost.	120	123	124	129	130	139	138	142	146
The total maintenance cost (JD).	20	60	32	8	48	50.4	18	22	8
The % of the total maintenance cost.	0.435	1.304	0.695	0.174	1.043	1.09	0.391	0.478	0.174
The salvage value (JD).	4600	4140	3726	3353.4	3018.06	2716.25	2444.63	2200.17	1980.15
The income of the device/ year.	31200	26900	23500	35400	24500	39500	7800	32800	29400
The inflation rate (%).	3.5	6.25	4.7	13.9	-0.7	4.48	4.15	4.42	5.29
The interest rate (%).	3.52	5.13	5.56	5.66	4.23	3.4	3.46	4.19	4.97
LCC (JD / year).	5548.41	5703.69	5721.29	5946	6018.62	6459.65	6387.79	6562.09	6737.64

Table 4.3.9

The costs summery for Nestoret 5050, Guido Rayos X.SA, Spain (Model 2) as calculated from the collected data from the operators and historical records

Cost category	Year										
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
The capital cost.	5000	4500	4050	3645	3280.5	2952.45	2657.205	2391.485	2152.336	1937.102	1743.392
The total operating cost (JD).	5318.52	5635.12	5712.61	5825.53	5833.94	6147.0	6135.94	6733.88	6614.68	6810.13	7034.46
The % of the operating cost to the capital cost.	106	113	114	117	117	123	123	135	132	136	141
Total maintenance cost	20	8	44	362	374	8	8	8	8	8	8
% of total maintenance cost.	0.4	0.16	0.88	7.24	7.48	0.16	0.16	0.16	0.16	0.16	0.16
The salvage value (JD).	5000	4500	4050	3645	3280.5	2952.45	2657.205	2391.485	2152.336	1937.102	1743.392
The income of the device/ year.	21800	33600	29900	4800	15900	35400	28000	39900	30100	32900	29400
The inflation rate (%).	1.6	2.6	3.5	6.25	4.7	13.9	-0.7	4.48	4.15	4.42	5.29
The interest rate (%).	2.75	2.49	3.52	5.13	5.56	5.66	4.23	3.4	3.46	4.19	4.97
LCC (JD).	5338.52	5643.123	5756.614	6187.53	6207.944	6155.005	6143.936	6741.879	6622.681	6818.13	7042.458

Table 4.3.10

Discounted LCC values for both infant incubator models, Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2), over the years 2007- 2013

	Year								
Model	2005	2006	2007	2008	2009	2010	2011	2012	2013
Air shields C450 (Model 1)	5548.41	5660.84	5630.25	7529.69	5249.38	7230.75	6859.74	6610.68	7557.19
Nestoret 5050 (Model 2)	5756.61	6141.05	6109.15	7794.35	5358.68	7546.66	7111.99	6868.62	7899.09

Table 4.3.11

Discounted LCC values for both infant incubators models, Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2), regarding to each model age

	Device age (year)			
Model	1	2	3	4
Air shields C450 (Model 1)	5548.41	5660.84	5630.25	7529.69
Nestoret 5050 (Model 2)	5219.69	5649.18	5756.61	6141.05

Table 4.3.12
Results of correlations for both models as obtained from SPSS17.0 program.

		Year	Air shields C450 (Model 1)	Nestoret 5050 (Model 2)
Year	Pearson Correlation	1	0.980	0.961
	Sig.(1-tailed)		.0001	0.0001
	N	9	9	11
Air shields C450 (Model 1)	Pearson Correlation	0.980	1	.893**
	Sig.(1-tailed)	0.0001		.001
	N	9	9	9
Nestoret 5050 (Model 2)	Pearson Correlation	0.961	0.893**	1
	Sig.(1-tailed)	0.0001	.001	
	N	11	9	11

Table 4.3.13
Results of ANOVA regression analyes as obtained from SPSS17.0 program

	Sum of squares	Degrees of freedom (df)	Mean square	F	Significance level (α)
		Air shields C450 (Model 1)			
Regression	1404156.67	1	1404156.67	165.53	0.0001
Residual	59381.39	7	8483.06		
Total	1463538.06	8			
		Nestoret 5050 (Model 2)			
Regression	2584976.49	1	2584976.488	108.55	0.0001
Residual	214316.956	9	23812.995		
Total	2799293.44	10			

Table 4.3.14
Results of regression coefficients for both models as obtained from SPSS17.0 program

	Unstandardized Coefficients		Standardized Coefficients		
	C	Std. Error	Beta	t-value	Sig.
		Air shields C450 (Model 1)			
(Constant)(A)	5355.68	66.912		80.04	0.0001
device age(B)	152.979	11.891	0.980	12.87	0.0001
		Nestoret 5050 (Model 2)			
(Constant)(A)	5321.84	99.791		53.33	0.0001
device age(B)	153.296	14.713	0.961	10.42	0.0001

Table 4.3.15
The expected LCC values for the next 5 years (2014 to 2018)

Year	Model	
	Air shields C450 (Model 1)	Nestoret 5050 (Model 2)
2014	6885.47	7161.394
2015	7038.449	7314.69
2016	7191.428	7467.986
2017	7344.407	7621.282
2018	7497.386	7774.578

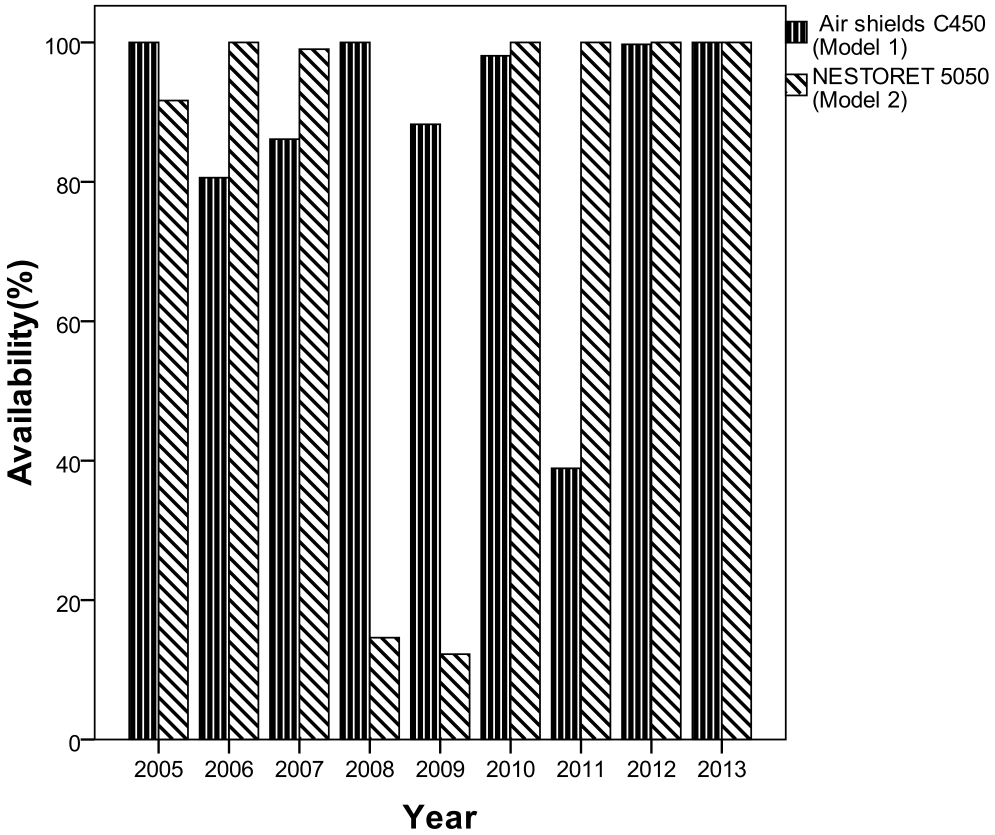


Figure 4.3.1
The availability % for both infant incubators models, Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2)

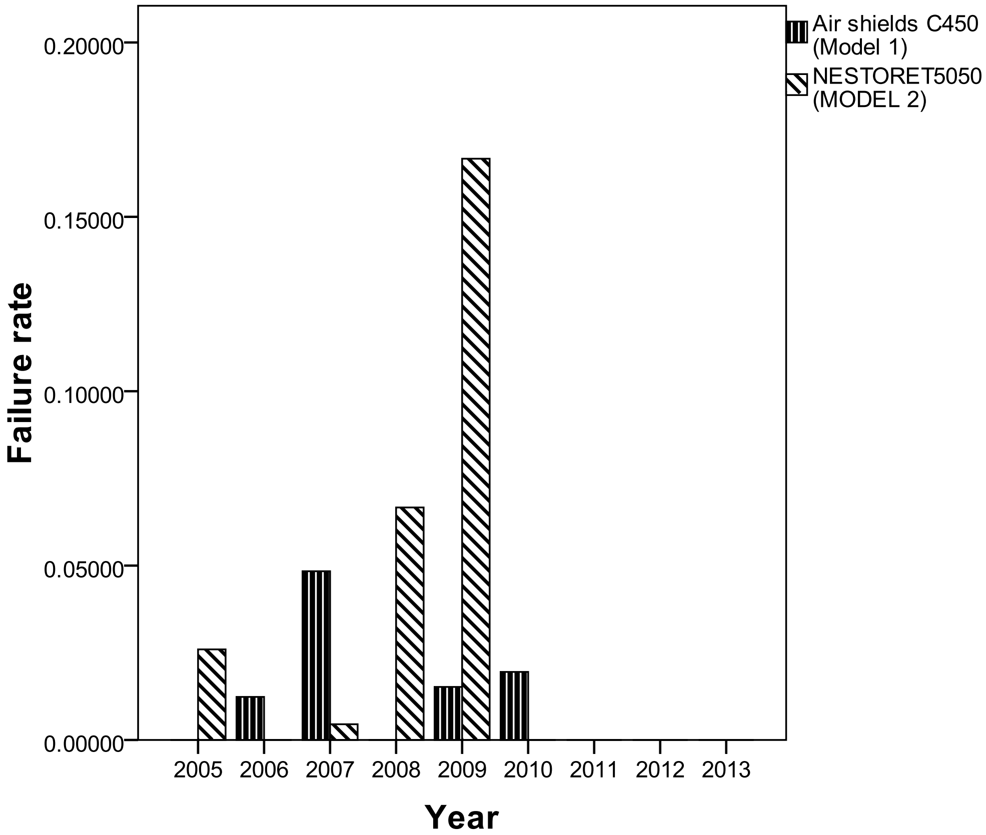


Figure 4.3.2
The failure rate for both infant incubators models, Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2)

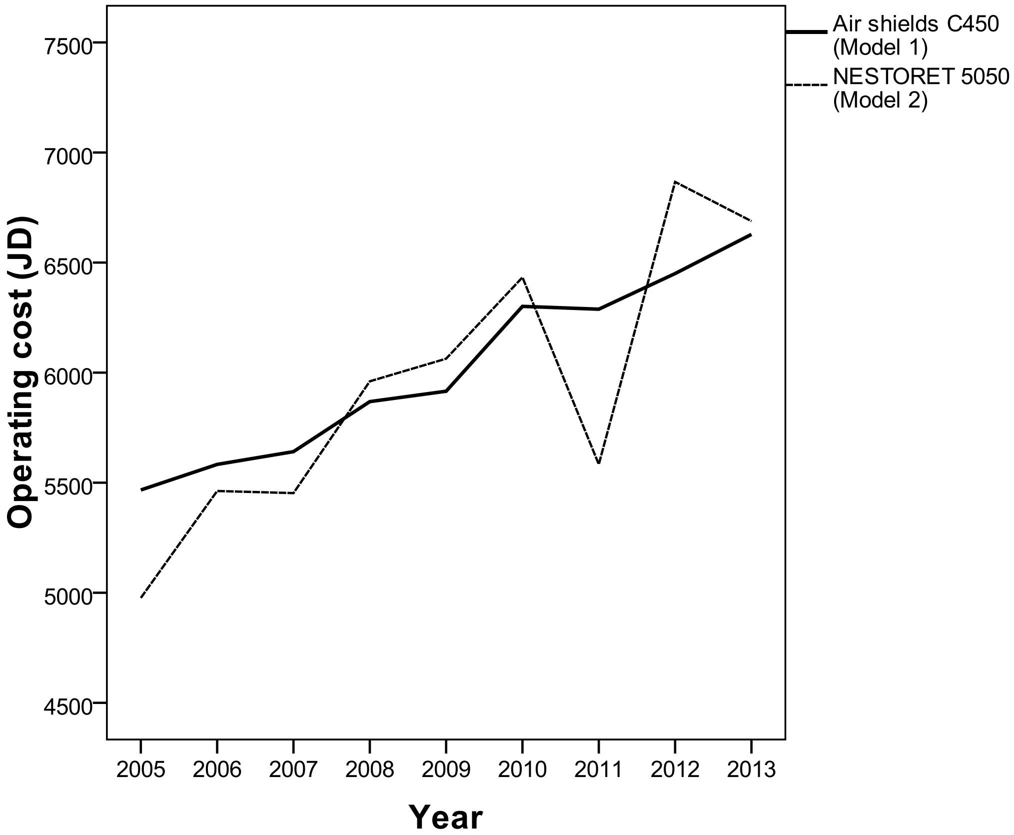


Figure 4.3.3
The operation cost for both infant incubators models; Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2)

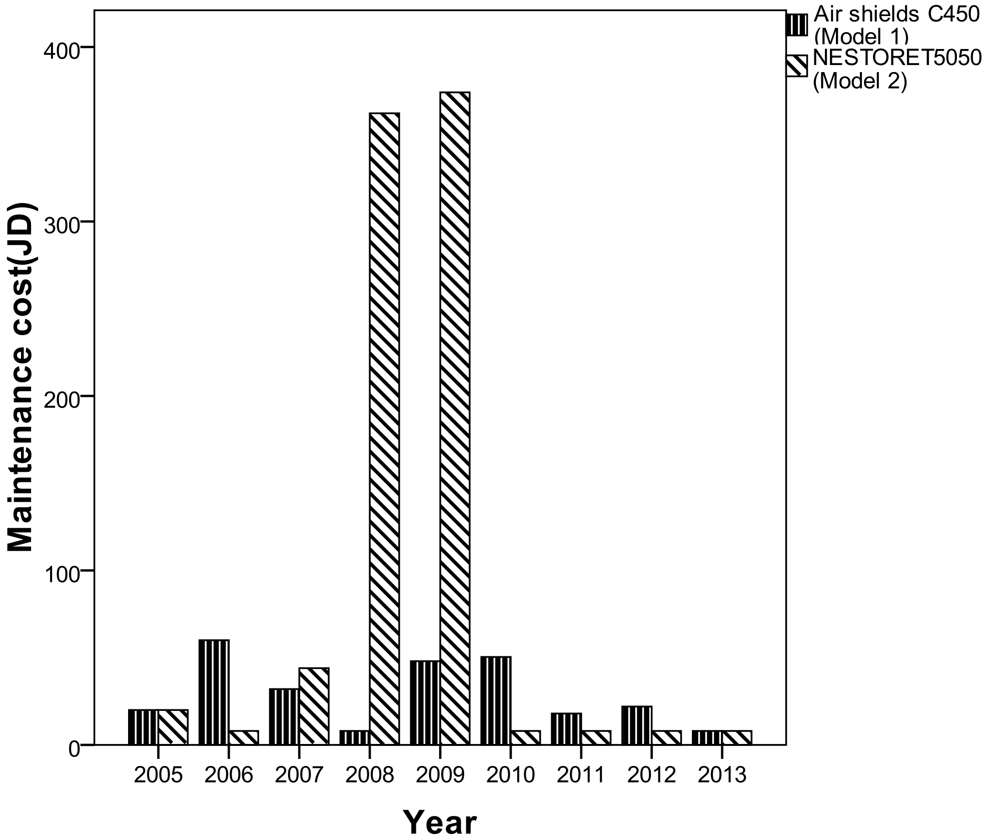


Figure 4.3.4
The maintenance cost for both infant incubators models; Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2)

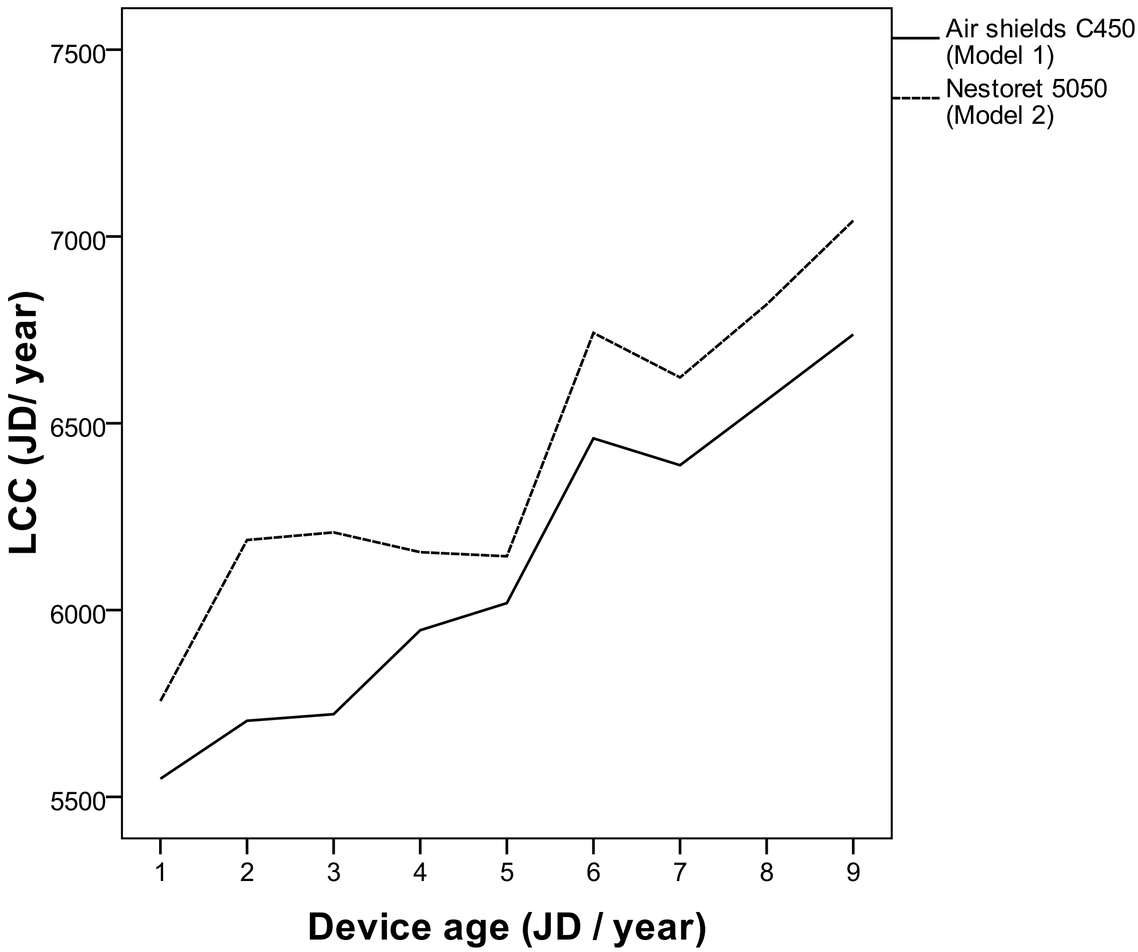


Figure 4.3.5
The LCC for both infant incubators models; Air shields C450, Vickers PLC Company, (Model 1) and Nestoret 5050, Guido Rayos X.SA, Spain (Model 2)

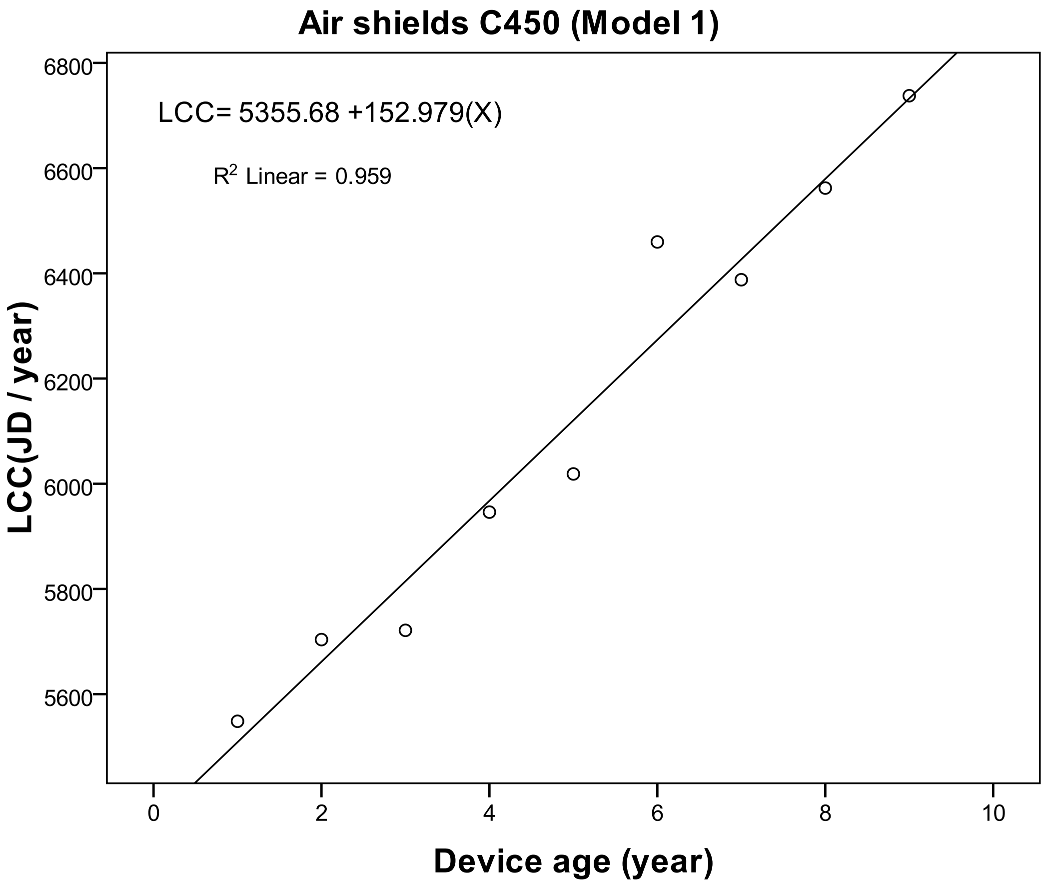


Figure 4.3.6
Scatter plot of LCC against the device age, together with a straight line regression for Air shields C450, Vickers PLC Company, (Model 1)

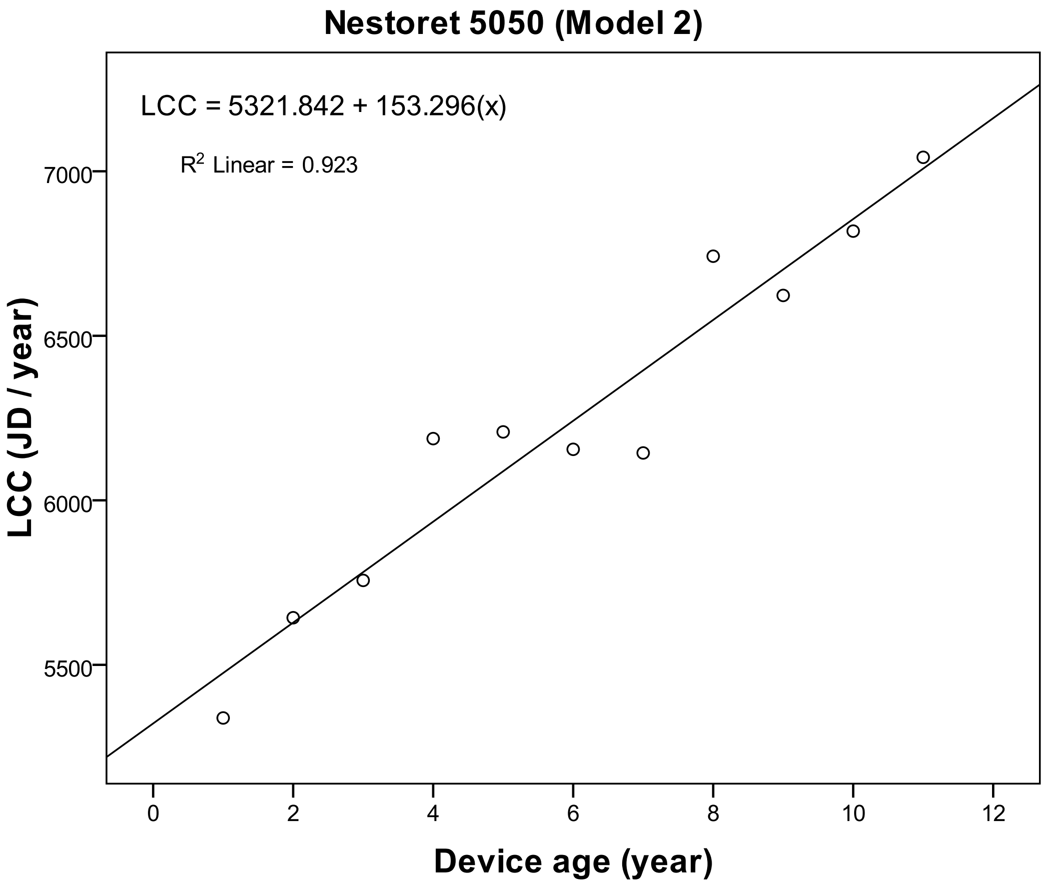


Figure 4.3.7
Scatter plot of LCC against the device age, together with a straight line regression for Nestoret 5050, Guido Rayos X.SA, Spain (Model 2)

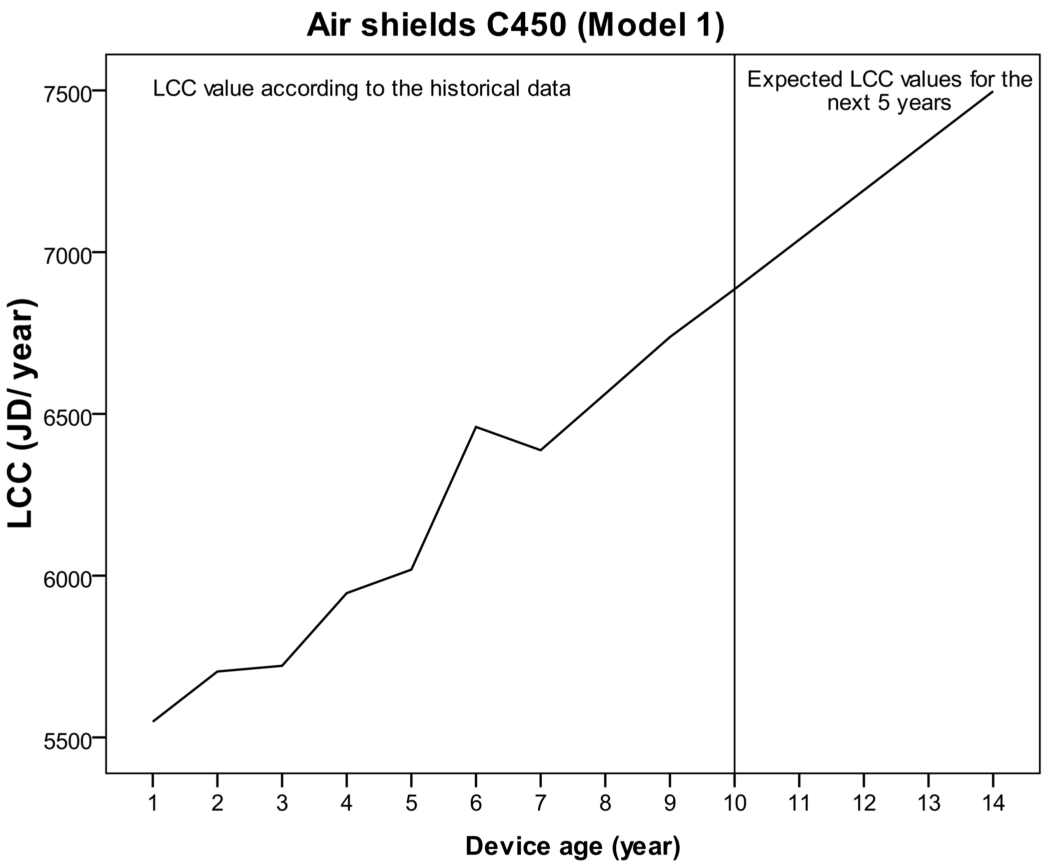


Figure 4.3.8
The previous LCC values from 2005 to 2013 and the future expected values from 2014 to 2018 for Air-shilds C450, Vickrs PLC Company, USA (Model 1)

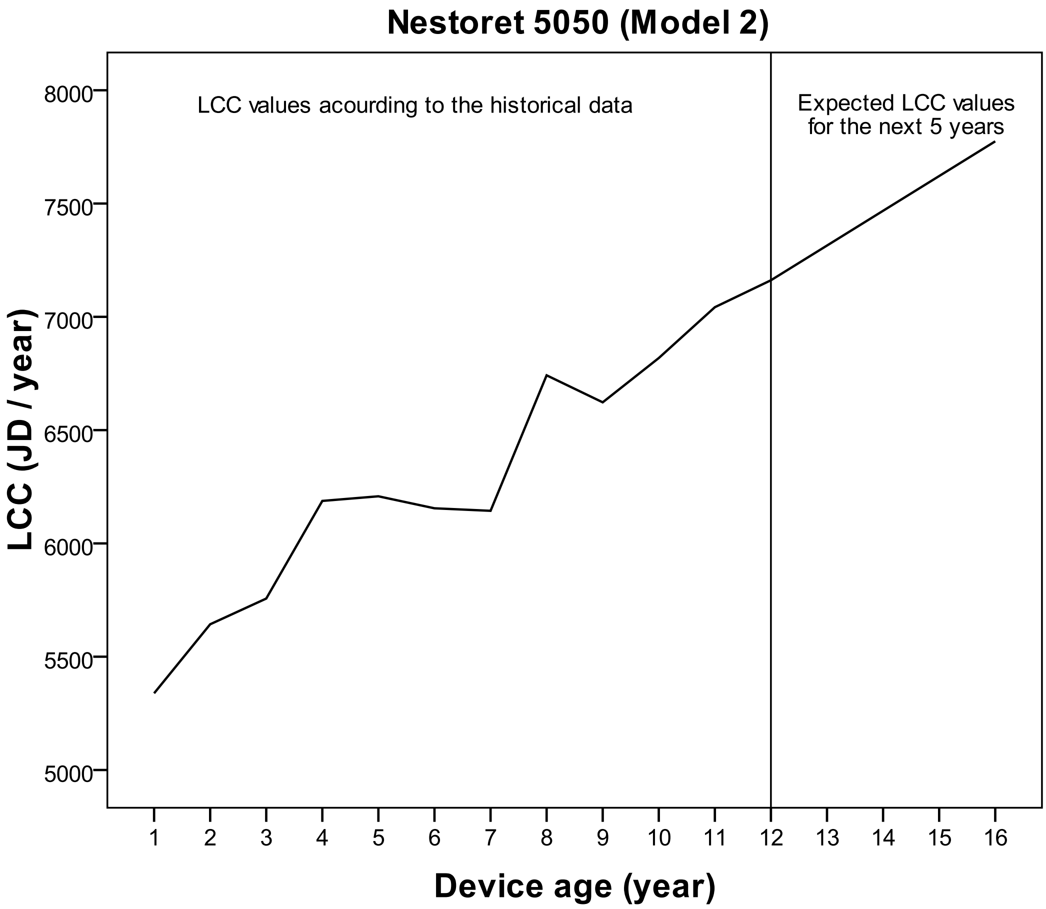


Figure 4.3.9
The previous LCC values from 2003 to 2013 and the future expected values from 2014 to 2018 for Nestoret 5050, (Model 2)

4.4 Conclusions and Recommendations

4.4.1 Conclusions

Efficient budget management of medical devices includes selection of better alternative with low maintenance and operation costs, which will lead in consequence to low LCC during the device lifespan. LCC data base provides basic information essential for decision making when a group of alternatives are available. Lack of LCC implementation might lead to select less economic medical device model which have difficulties in acquiring their spares parts and/or those devices with high maintenance cost and consequently high LCC during the device life span. The findings from the data collected in this study revealed that LCC could be implemented efficiently to maintain the hospital medical devices assets in a cost effective

manner which is aimed at long-term preservation of the asset value. The major outcomes of the current study include:

1. The calculation of LCC in this study is not difficult if the historical records are available for data related to operating and maintenance costs. Results of this study reveal that the use of LCC calculations is an effective tool to help decision makers in selecting the best alternative among a group of alternative models.
2. If reliable historical records are available, it also possible to predict future LCC costs. In this study, we were able predict future LCC values using linear regression equations. The results always showed an increase in LCC by increasing the device age, which is logical because of the depreciation of the device and the need for major maintenance actions during the device life span.
3. Results showed that LCC and device age are linearly related indicating the increase of the cost to maintain the device in service by increasing the device age. From the regression equation, the expected LCC values for the next five years were estimated. LCC values would substantially increase during the following years indicating the need for more maintenance costs during the following years.
4. The high initial cost is not necessarily indicating the best or the worst alternative. In the electrolyte case and the infant incubator the best alternative were those with lower initial cost. However in the X –ray case study the best alternative was with the higher initial cost. Therefore, the availability of LCC information for particular devices is vital for decision-making to justify devices and process selection based on total costs rather than the initial purchase price as the cost of operation, maintenance, and disposal costs might exceed the initial cost of the medical device.
5. Most commonly, consumable power cost and the maintenance cost are the main cost factor in life cycle cost of the medical device Therefore, when comparing the annual LCC values for each two alternative models, the key effective cost categories affecting LCC were the consumable power cost and the maintenance cost. If these factors are minimized, it will improve the life time performance of the medical device and will substantially reduce the LCC.

4.4.2 Recommendations and Perspectives

The selection of medical devices in government tenders does not take into account the life cycle costing of various alternatives. Therefore, LCC should be considered during device selection process to minimize the maintenance and operation cost, and also to select better alternatives with

low initial purchasing costs. LCC data bases are not available for tender teams who are take the responsibility of the device selection. Therefore, the major recommendations and perspectives from this study are:

1. The same procedure (Kauffman approach) used in this study could be applied on other sets of medical device to select the better alternatives from a group of devices. Databases and historical records are available for other devices and consequently reliable estimate of LCC could be obtained.
2. In Jordan, Medical Device Directorate, Royal Jordanian Association has rich documented data that could be efficiently used in LCC estimation for medical devices. Data on medical devices are continuously collected and updated over time, using this data can become more reliable and the LCC analysis more trustworthy, establishing a LCC data base for these medical devices.
3. In Jordan, there is no documented information on medical devices LCC analysis that represents a main asset in the health care system. Moreover, LCC analysis is not applicable in governmental tenders. Consequently, there is a need to manage the medical devices selection in health care systems in an efficient manner, which will improve the quality of healthcare service that can be greatly influenced by the way in which devices is purchased and managed.

References

Allouche, E.N., and P. Freure. 2002. Management and Maintenance Practices of Storm and Sanitary Sewers in Canadian Municipalities. ICLR Research, Department of Civil and Environmental Engineering; Geotechnical Research Centre; The University of Western Ontario.

Andrew, E. 1974. Microwave Landing System Integration Study. Report No. GSE-SE- 74-1, Air Force Institute of Technology, Wright Patterson Air orce Base, Oh.

Asiedu, Y., and P. Gu. 1998. Product life cycle cost analysis: State of the art eview. Int. J. Prod. Res. 36: 883–908.

AVL Scientific Corporation. 1996. 9180 Electrolyte Analyzer Operator ' s Manual.

Barringer, H.P. 2003. A Life Cycle Cost Summary. p. 1–10. *In* International Conference of Maintenance Societies (ICOMS®-2003. Maintenance Engineering Society of Australia, A Technical Society Of The Institution of Engineers, Australia.

Barringer, H.P., P.E. Barringer, I. Associates, and T.X. Humble. 1997. Life Cycle Cost & Reliability for Process Equipment. p. 28–30. *In* 8th Annual Energy Week Conference & Exhibition. American Society of Mechanical Engineers, And Penn Well Publishing, George R. Brown Convention Center Houston, Texas, USA.

Barringer, H., and D. Weber. 1996. Life cycle cost tutorial. p. 1–58. *In* fifth international conference. Marriott Houston Westside Houston, Texas, USA.

Boussabaine, A., and R. Kirkham. 2004. Whole Life-Cycle Costing: Risk and Risk Responses. Blackwell Publishing, Oxford.

Bronzino, J.D. 1992. Managgement of medical technology : a primer for clinical engineer. Butterworth, Heinemann.

Bronzino, J.D. 2006. The biomedical engineering handbook. 3rd editio. CRC press in Taylor and Francis group.

Buys, A., M. Bendewald, and K. Tupper. 2010. Life Cycle Cost Analysis: Is it Worth the Effort? American Society of Heating, Refrigerating and Air Conditioning Engineer, Inc., USA (Report).

Chien, C., Y. Huang, and F. Chong. 2010. A framework of medical devices management system for in-house clinical engineering department. Buenos Aires, Argentina.

Commonwealth Scientific and Industrial Research Organization (CSRIO) and Flagships. 2003. Pipeline Asset & Risk Management System (PARMS). Australia (Report).

Dell'Isola, A.J., and S.J. Kirk. 1995. Life Cycle Costing for Design Professionals. McGraw-Hill Companies, New York, USA.

Dhillon, B.S. 2008. Mining Equipment Reliability, Maintainability, and Safety. Springer, The Netherland.

Dhillon, B.S. 2010. Life Cycle Costing for Engineers. Taylor and Francis Group, USA.

Dixon, T. E. and Anderson, R.H. 1976. Implementation of the Design to Cost Concept. p. 224–229. *In* Amazon Publishing.

Edward, D.J., G.D. Holt, and F.C. Harris. 2000. Estimating life cycle plant maintenance cost. Constr. Manag. Econ. 18: 427–435.

Fisher, I. 1961. The Theory of Interest, as determined by Impatience to Spend Income and Opportunity to Invest it. New York: A. M. Kelley.

Gager, A. 2012. Embracing A Life-Cycle Cost Analysis, Facilities Management. Facility Maintenance Decisions (FMD), Report.

Ganapathy, V. 1983. Life-cycle Costing Applied to Motor Selection. Process Eng.: pp 51–52.

Gautam, K.P. 2009. Life-Cycle Cost Analysis of Home- Ownership, Ph.D. Thesis, University of Hawai, USA. : 411.

Gluch, P., and H. Baumann. 2004. The life cycle costing (LCC) approach: A conceptual discussion of its usefulness for environmental decision-making. Build. Environ. 39: 571–580.

Guido-Rayos-X.SA. 2002. Incubator. Spain.

Hazlitt, H. 1965. What You Should Know About Inflation. 2nd Editio. D. Van Nostrand Company, Inc., Toronto, Canada.

Hoffmann, J., and P.. Abbe. 2013. Lifecycle Costs for Capital Equipment In the CPI. Bensonvill, USA (Report).

Illinois, S. of, and C.D. Board. 1991. Life Cycle Cost Analysis Manual. Goverment Printing Office, Washington, USA (Report).

ISO 14971. 2007. Plain English Dictionary-Plain English medical device risk management definition, Medical device quality management.

Ison, E.., and A. Miller. 2000. The use of LCA to introduce Life-Cycle thinking into deision-making for the purcJhase of medical devices in the NHS. J. Env. Assmt. Pol. Mgmt. 2(4): 453–476.

Janz, D., W. Sihn, and H.-J. Warnecke. 2005. Product Redesign Using Value-Oriented Life Cycle Costing. CIRP Ann. - Manuf. Technol. 54: 9–12.

Kabbani, I.A. 1993. Decision Support Life-cycle Analysis System in Building Design, Ph.D. Thesis, University of Colorado, Boulder, USA.

Kaya, E. 2009. Life Cycle Cost Awareness Among Architects: The Case Of Turkey, M.Sc. Thesis, Izmir Institute of Technology. Turkey. : 411.

Levander, E., J. Schade, and L. Stehn. 2014. Life cycle costing for buildings: theory and suitability for addressing uncertainties about timber housing. Luleå, Sweden (Report).

Lindholm, A., and P. Suomala. 2004. The possibilities of life cycle costing in outsourcing decision making. Tampere University of Technology, Finland (Report).

Logistics Management Institute (LMI). 1965. Life Cycle Costiong in Equipment Procurment. Report no. LMI task 4c-5. Washington, D.C. (Report).

Medica Corporation. 2003. EasyLyte Plus.

National Institute of Standards and Technology-NIST. 1996. Life cycle costing manual for the Federal energy management program. Gaithersburg, MD 20899 (Report), USA.

NATO Science and Technology organization. 2007. RTO-TR-SAS-054 - Methods and Models for Life Cycle Costing,. USA (Report).

Norsok Standard. 1996. Life cycle cost for systems and equipment, Rev.1. Norway (Report).

Panneerselvam, R. 2012. Engineering Economics. Asoke K. Ghos, PHI Learning Private Limited, New delhi.

Park, J.-H., K.-K. Seo, D. Wallace, and K.-I. Lee. 2002. Approximate Product Life Cycle Costing Method for the Conceptual Product Design. CIRP Ann. - Manuf. Technol. 51: 421–424.

Parker, K.R.A. 1991. Generic life-cycle cost model for an embedded controller, M. Sc. Thesis, Texas Tech University, USA.

Rahman, S., and D.J. Vanier. 2004. Life cycle cost analysis as a decision support tool for managing municipal infrastructure. p. 1–12. *In* CIB 2004 Triennial Congress. Toronto, Ontario, May 2-9.

Regulinski, T. L. and Gupta, Y.P. 1983. Reliability Cost Estimation: Managerial Perspectives. IEEE Trans. Reliab. 22: 276–281.

Reidy, R., V. Provost, M. Davis, R. Coony, S. Gould, C. Mann, B. Sewak, A. Daly, and S. Lewis. 2005. Guidelines for life cycle cost analysis. Illinois, USA.

Salem, O., S. AbouRizk, and S. Ariaratnam. 2003. Risk-based Life-cycle Costing of Infrastructure Rehabilitation and Construction Alternatives. J. Infrastruct. Syst. 9: 6–15.

Seyffer, C.J., C. Farr, and N.J. Riverdale. 2010. Air-filter life-cycle cost. Heating/Piping/Air Conditioning HPAC Engineering newsletter, Penton Publishing (Report).

Shimadzu Corporation. 2000. Bucky X- ray.

Steen, B. 2005. Environmental costs and benefits in life cycle costing. Manag. Environ. Qual. An Int. J. 16: 107–118.

Sullivan, G.P., R. Pugh, A.P. Melendez, and W.D. Hunt. 2002. Operations and maintenance best practices a guide to achieving operational efficiency. USA (Report).

Toshiba Corporation. 2005. Bucky X- ray.

Vickers company PLC, U. 2000. Infant Incubator.

Woodward, D.G. 1997. Life cycle costing--theory, information acquisition and application. Internattonal J. Proj. Manag. 15: 335–344.

Yeh, T.-H., and S. Deng. 2012. Application of machine learning methods to cost estimation of product life cycle. Int. J. Comput. Integr. Manuf. 25: 340–352.

Zimmermann, M. 2005. Life Cycle Costing. GRIN Verlag, Friedrich-Alexander-Universität ErlangenNürnberg, Norderstedt.

Web sites

[1] http://www.praxiom.com/iso-14971-terms.htm

[2]http://reliabilityweb.com/index.php/maintenance_tips/how_to_prevent_rcm_from_turning_into_really_costly_maintenance/

[3] www.microsoft.com

[4] www.sohar.com

[5] www.isographdirect.com

[6] www.eere.energy.gov/femp

[7] www.relexsoftwar.com

[8] www.liv.ac.uk/abe/index.html

[9] http://en.wikipedia.org/wiki/MTBF

[10] http://www.healthofchildren.com/U-Z/X-Rays.html

[11]http://www.livestrong.com/article/233496-what-are-the-functions-of-an-infant-infant incubator